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A Rigid, Perforated Plate Oil Boom for High Currents

Shell Development Co, Houston, Tex

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A boom capable of diverting oil spills toward shore in a 3-knot (1.5 m/s) river or tidal current has been developed. Loss of No. 2 and No. 4 Fuel Oil at this velocity is typically less than 15 percent when the angle of the boom is 45 degrees to the shoreline. In contrast, conventional booms lose this amount at only 1 knot (0.5 m/s).

Good performance at high currents is achieved by placing a baffle upstream of a conventional flat plate boom. The baffle, an inclined, perforated plate, is used to create a flow-sheltered region where the oil layer thickens. A continuation of the inclined plate baffle forms the "floor" of the sheltered region to control the flow rate of exiting water. Horizontal plates immediately behind the baffle reduce water down-flow.

The boom is made up of 8-foot (2.4 m) long, rigid sections similar in plan view to a floating dock module. The length of the boom depends upon the number of modules pinned together side by side. Floating suction or sorbent rope collection devices may be used to remove accumulated oil from the flow sheltered region and increase "capacity".

Drawings are provided to permit construction by others.

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A RIGID, PERFORATED PLATE OIL BOOM FOR HIGH CURRENTS

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report describes an improved boom capable of directing spills of oil or floating hazardous materials toward shore in a 3-knot (1.5 m/s) river or tidal current. This capability is about double that of conventional booms. The applied research leading to its development and the confirming tests of its capability at EPA's OHMSETT facility are also described. Detailed information and construction drawings are provided to enable anyone with a need to protect high current streams from spills to build a duplicate boom for their own use, and to enable researchers with related interests to follow the developmental rationale. For additional information, please contact the U.S. EPA Oil and Hazardous Materials Spills Branch, Edison, N. J. 08817.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

A boom capable of diverting oil spills toward shore in a 3-knot (1.5 m/s) river or tidal current has been developed. Loss of No. 2 and No. 4 Fuel Oil at this velocity is typically less than 15 percent when the angle of the boom is 45 degrees to the shoreline. In contrast, conventional booms lose this amount at only 1 knot (0.5 m/s).

Good performance at high currents is achieved by placing a baffle upstream of a conventional flat plate boom. The baffle, an inclined, perforated plate, is used to create a flow-sheltered region where the oil layer thickens. A continuation of the inclined plate baffle forms the "floor" of the sheltered region to control the flow rate of exiting water. Horizontal plates immediately behind the baffle reduce water down-flow.

The boom is made up of 8-foot (2.4 m) long, rigid sections similar in plan view to a floating dock module. The length of the boom depends upon the number of modules pinned together side by side. Floating suction or sorbent rope collection devices may be used to remove accumulated oil from the flow sheltered region and increase "capacity".

One or more modules can also be attached to vessels of opportunity and used as a skimmer.

Construction drawings are included with this report.

This report was submitted in fulfillment of Program Element No. 1BB041, Contract Number 68-03-0331 by Shell Development Company under the sponsorship of the Environmental Protection Agency. Work was completed as of May 1976.

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To our valuable technicians, Jim Smith, Dean Henning, and Bob Hammond, who made the prototype work well, we also offer thanks.

I. INTRODUCTION

The most effective way of controlling the movement of oil spilled on water is to use floating oil barriers, or booms. Although booms have been significantly improved in recent years, a fundamental problem remains in containing and diverting oil in high currents. Many of our rivers and tidal estuaries have currents in excess of two knots and conventional booms do not perform well at such velocities.

A radically different rigid, modular boom has been designed and verified by test for permanent installation in high currents. The design is based upon placing a baffle immediately upstream of a barrier to slow down the surface flow and, as a consequence, contain oil between at higher currents than conventional booms.

II. CONCLUSIONS

1. A high-current boom capable of diverting No. 2 and No. 4 fuel oil to shore at 3 knots (1.5 m/s) with typically less than 15 percent of the applied oil loss under the boom has been developed by Shell with funding from the U.S. Environmental Protection Agency (EPA).

2. This boom design depends upon an inclined, 50 percent perforated-plate baffle just upstream of a solid vertical-plate barrier. The flow-sheltered region between the baffle and the barrier has a perforated plate as a bottom, slowing the exiting water. In addition, horizontal flow control plates immediately behind the inclined baffle reduce water downflow and minimize turbulence.

3. The boom profile is built into 8-foot (2.4 m) wide rigid sections and linked together like a floating marina dock.

4. A primary application for this high-current device is its use as a permanently deployed diversionary boom, perhaps downstream of an oil loading/unloading dock. A standard skimmer, used in the flow-sheltered region of the boom to recover oil accumulated, will increase the boom's effectiveness.

5. Boom modules can be attached to vessels of opportunity for use as a temporary emergency skimmer. They can also be placed in a specially designed vessel and used as a permanent inshore skimmer.

6. The boom design is based on extensive full-scale experimentation and testing at the Shell current and wave tanks. Principal confirming tests were conducted at the EPA's OHMSETT Facility.

III. RECOMMENDATIONS

1. A single boom module should be fabricated according to the field-type design resulting from this program. The module, a "heavy-duty" version of that tested, should be tow-tank tested to make a final check of the flotation/weight and adequacy of the design (Figures 6a and 6b). Minor corrections should be made if needed.

2. Additional modules should then be fabricated and installed (pinned together to obtain the total length needed) in at least one suitable field location where boom performance can be evaluated in a real-life situation.

IV. RIGID, PERFORATED-PLATE BOOM DESIGN SUMMARY

DESCRIPTION

The forty-foot-long high-current boom section shown during tank testing in Figures 1 and 2 is a major result of a development program conducted by the Pipeline Research and Development Laboratory of Shell Development Company for the Industrial Environmental Research Laboratory of the U. S. Environmental Protection Agency under Contract Number 68-03-0331.

The rigid boom is formed by joining modules side-by-side (Figure 3). A typical four-foot wide module is shown in Figure 4. Design features are revealed in Figure 5. Upstream of a conventional flat-plate barrier the design incorporates a perforated-plate baffle to absorb part of the kinetic energy of water flow that a barrier alone normally experiences. A reduced-velocity region is created between the upstream perforated plate baffle and the downstream barrier. In a 3-knot (See English-Metric Conversion Table, Appendix G) free-stream current, for instance, currents of less than 0.6 knots have been measured in the reduced velocity region. Because loss of oil past a barrier is a function of the local velocity, oil does not easily escape under this barrier.

Streamlined flotation incorporated in the forward part of the profile and flotation aft of the rear barrier combine to achieve the proper still-water alignment of the boom. A planing, perforated bow adds to the dynamic stability of the boom in combined waves and currents. Approaching oil readily enters the 50 percent open-area bow and flows into the reduced velocity region, rather than escaping under the boom. Once inside the reduced-velocity region, oil thickens to facilitate removal operations. Contained water exhausts downward through a 20 percent open-bottom closure plate.

PERFORMANCE IN CURRENTS

Based on extensive full-scale testing both at Shell's wave-tow tank in Houston, Texas and EPA's OHMSETT facility in Leonardo, New Jersey, we recommend the design summarized in Figure 6 for field applications. This design differs from that tested only in strength, durability and handleability considerations.

Figure 7 contains performance data for a high-current boom based on selected tank test results. In certain cases extrapolations are made to cover a larger range of spilled oils. More detailed results are included in Section VII.

The final design evolved from a careful analysis using flow diffusion and boom diversion principles to enhance the control of spilled oil in high currents. Initially two specific flow diffusion concepts were investigated: an inclined, perforated plate baffle and a stub-tube array baffle. In the experimental program each concept was evaluated and systematic alterations were made reflecting what was learned from previous tests. This interactive "feedback" process yielded somewhat optimized configurations for the two concepts. The inclined, perforated plate baffle - quite different looking from the initial concept - proved to be the better baffle-boom of the two for high currents. Descriptions of these basic experimental studies are found in Section VI.

PERFORMANCE IN WAVES AND DEBRIS

Test data described in Section VI indicate that small choppy waves, having periods of up to 2 seconds have only minor effect on the percentage of oil lost. Short waves (with the exception of those 10-foot long waves which excite the boom's natural frequency) impact the boom, and the boom responds like a breakwater, creating a much calmer area within the quiet region of the boom and behind it. In wave periods longer than 2 seconds, the boom will tend to follow the water surface like a boat, being limited by the freedom of motion of the connections when the direction of wave propagation is not normal to the boom. This boom is best suited for permanent service in waters where waves are generally less than 1 foot high.

The high-current boom is designed to allow current-borne debris to slide past underneath. Nevertheless, we expect that buoyant debris will accumulate in front of the boom. This debris must be cleared either by manual removal or by opening the boom to allow debris to pass on. The sturdy boom design plus spring-like cable moorings should avoid damage from debris collisions with the boom.

OIL RECOVERY TECHNIQUES

Oil transported by fast-moving waters and diverted shoreward by the high-current boom accumulates rapidly. Means must be provided in a typical field installation to rapidly recover oil as it accumulates.

The high-current boom is compatible with virtually any type of skimmer that will fit within it. For light oils it is appropriate to use a floating suction skimmer. There are a variety of floating suction skimmers that can be used with this boom. Additionally, Shell has developed one for other purposes (1) that is also suitable for this application.

Adsorbent belts - because of the nature of oil adhesion - work better on more viscous oils such as Bunker "C". An example is the mop-like adsorbent rope belt shown in Figure 8. The rope belt is operated in a closed-loop fashion inside the entire length of boom and oil is wrung from the belt and recovered at the shore.

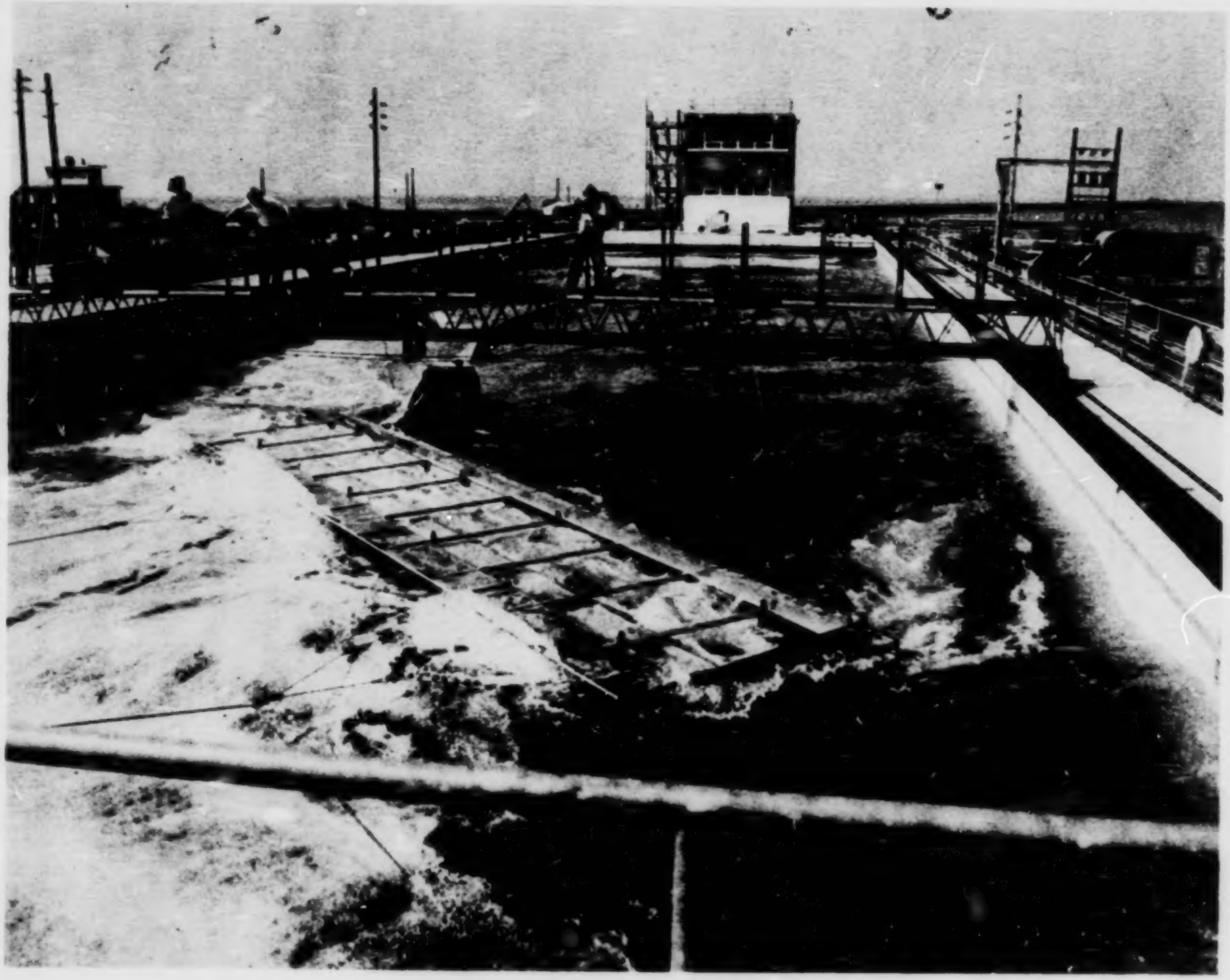


FIGURE 1 - TESTING IN WAVES WITH NO. 2 FUEL OIL AT OHMSETT

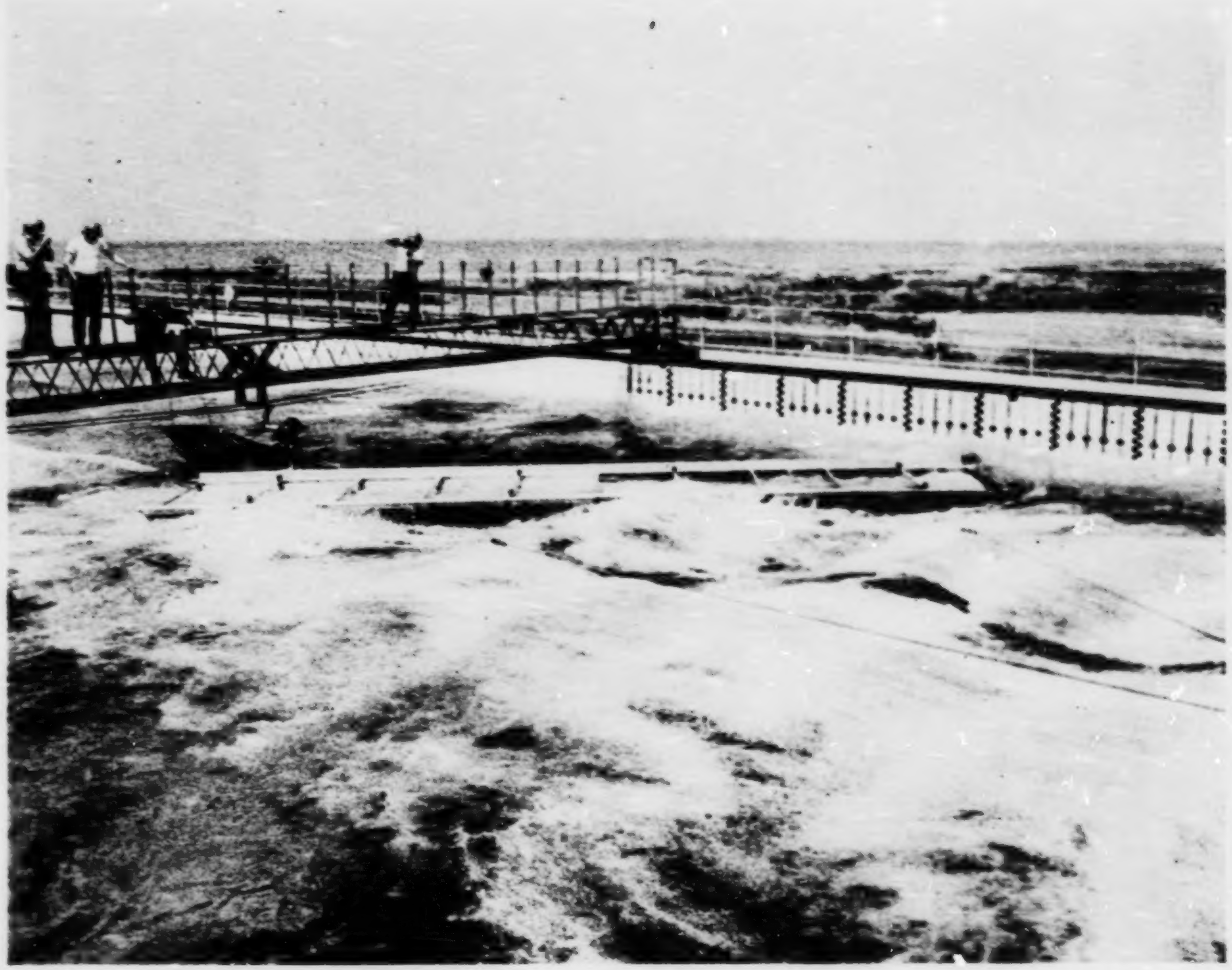


FIGURE 2 - TESTING IN WAVES WITH NO. 2 FUEL OIL AT OHMSETT

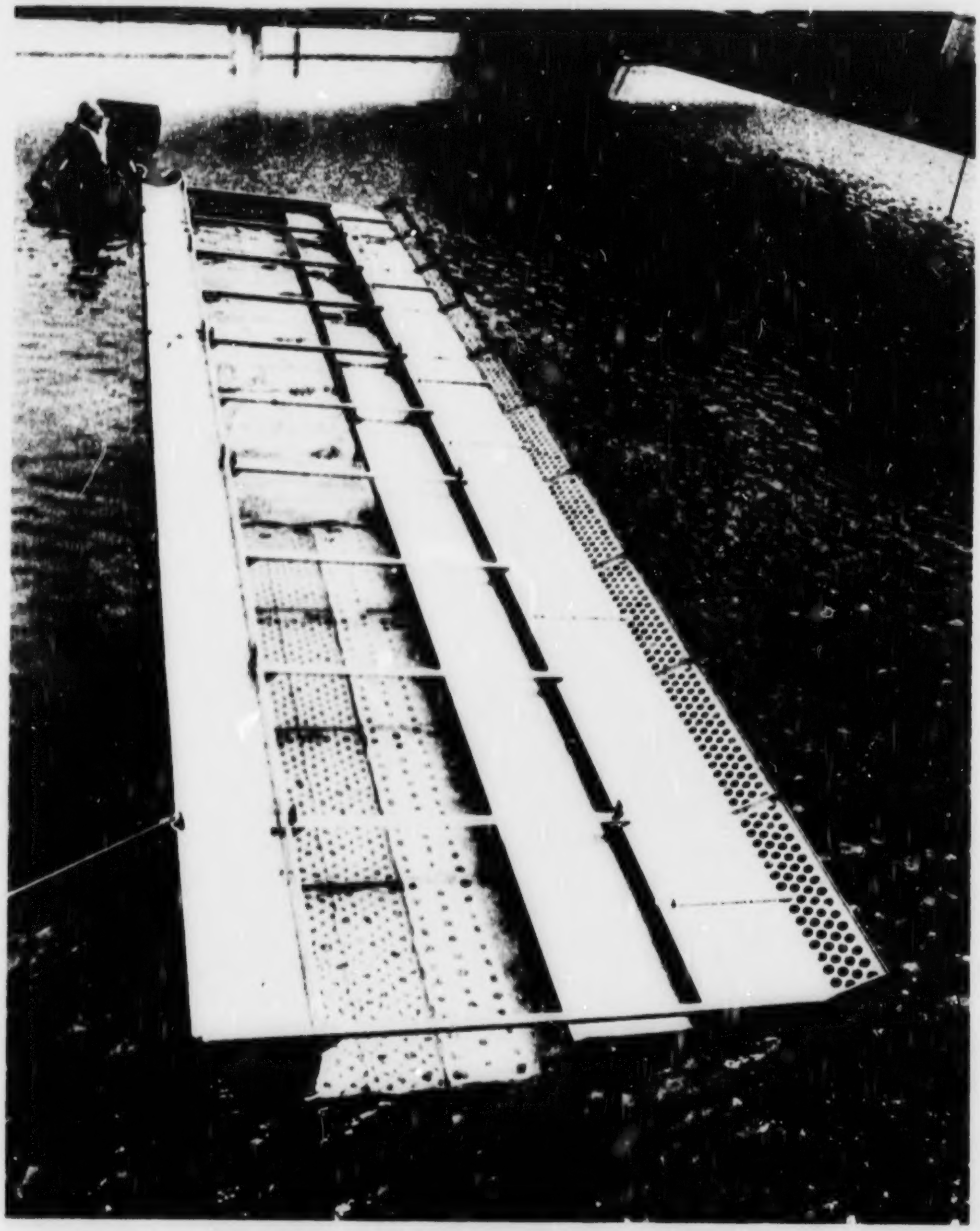


FIGURE 3 - TEN MODULES JOINED TO MAKE ONE RIGID SECTION OF BOOM (SHOWN FLOATING IN A RESTING POSITION - NO CURRENT AND NO WAVES)

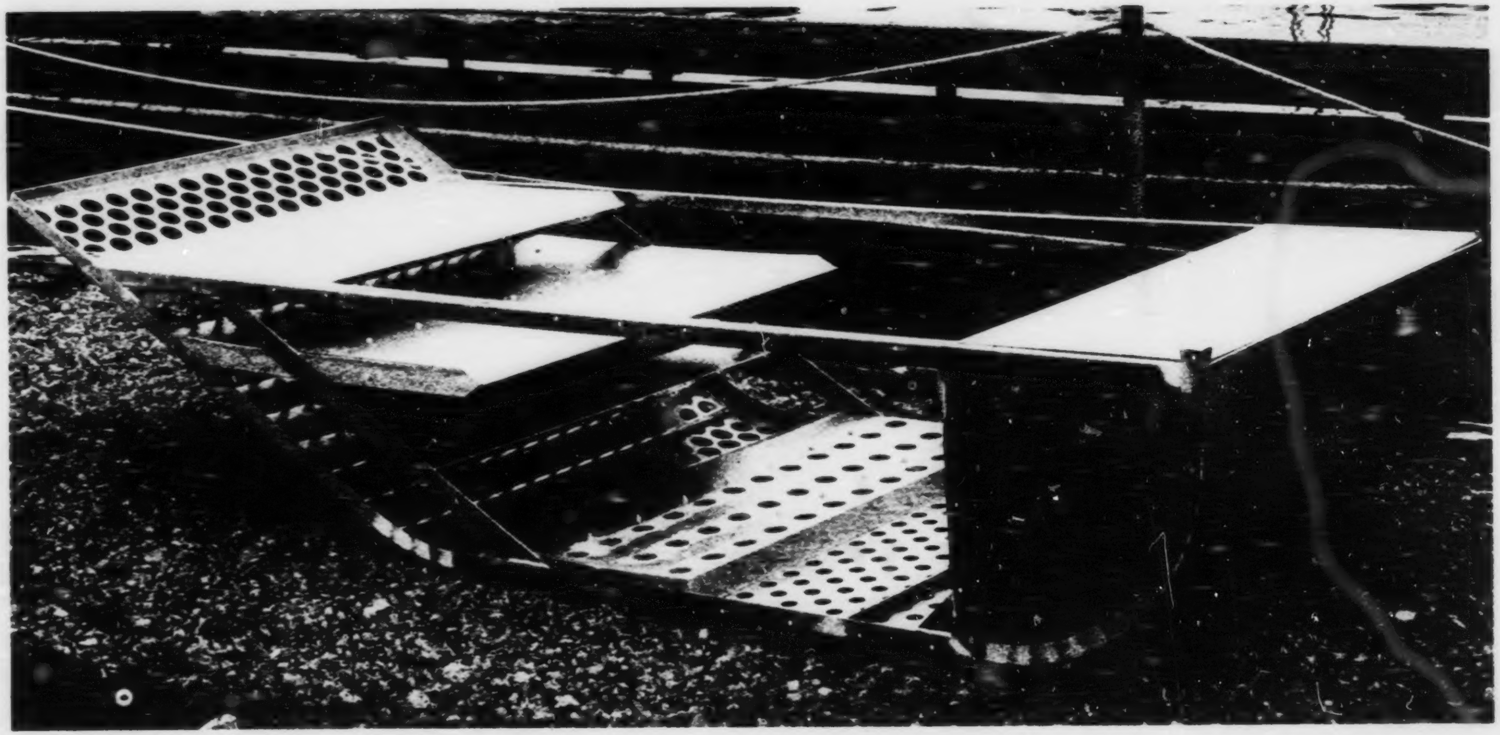


FIGURE 4 - FOUR-FOOT-WIDE HIGH CURRENT BOOM TEST SECTION

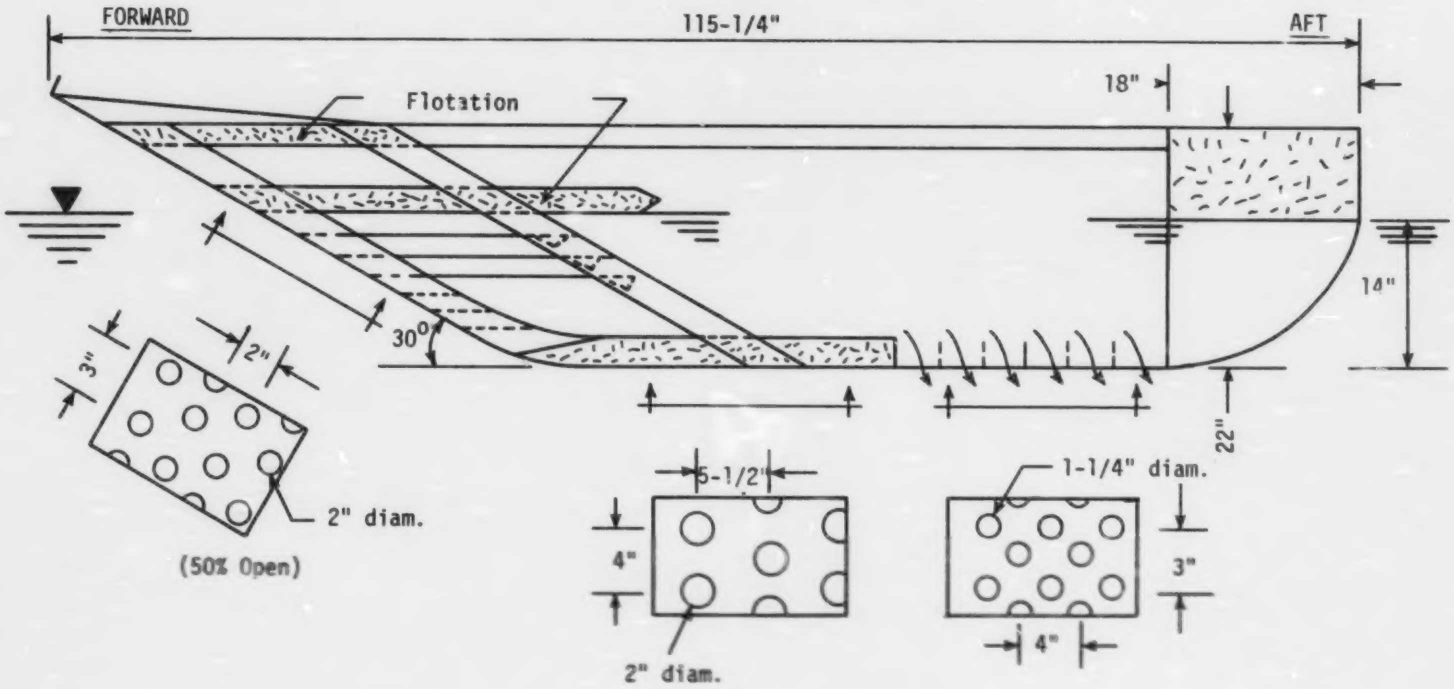

FORWARD
115-1/4"
AFT
18"
Flotation
14"
30°
3"
2"
2" diam.
(50% Open)
22"
5-1/2"
4"
2" diam.
1-1/4" diam.
3"
4"

FIGURE 5 - PROFILE OF THE RIGID, PERFORATED PLATE BOOM

NOTE: Figure 6 on pages 12-15.

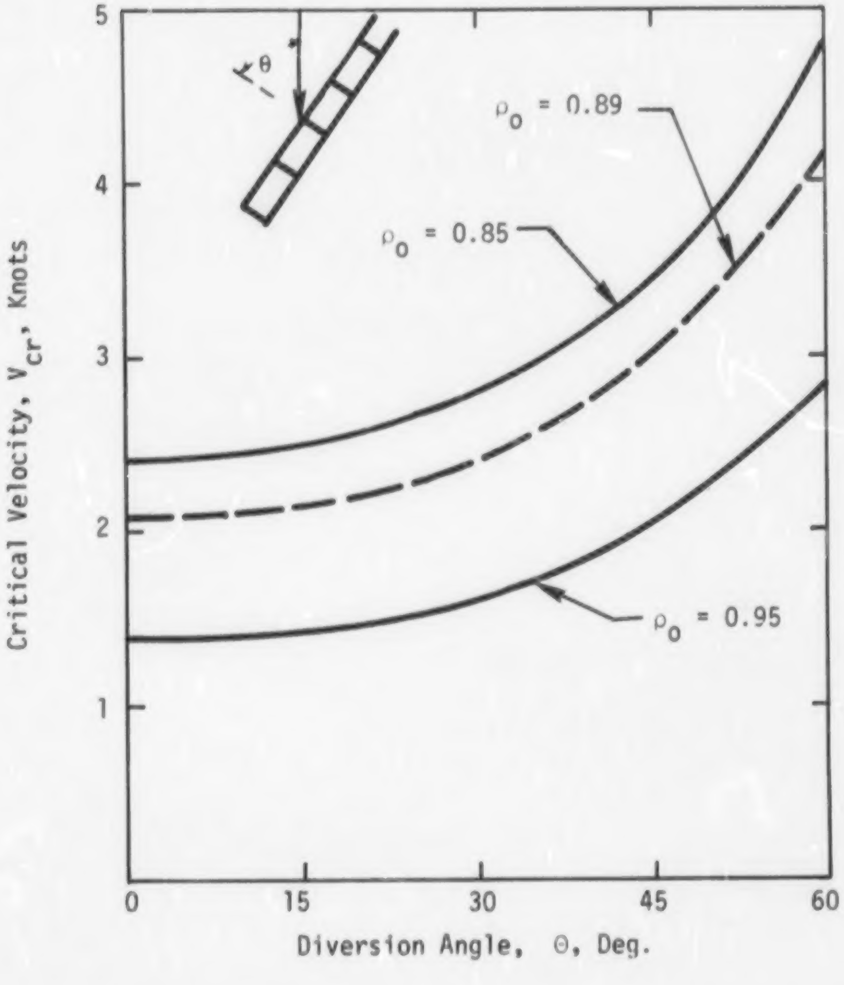
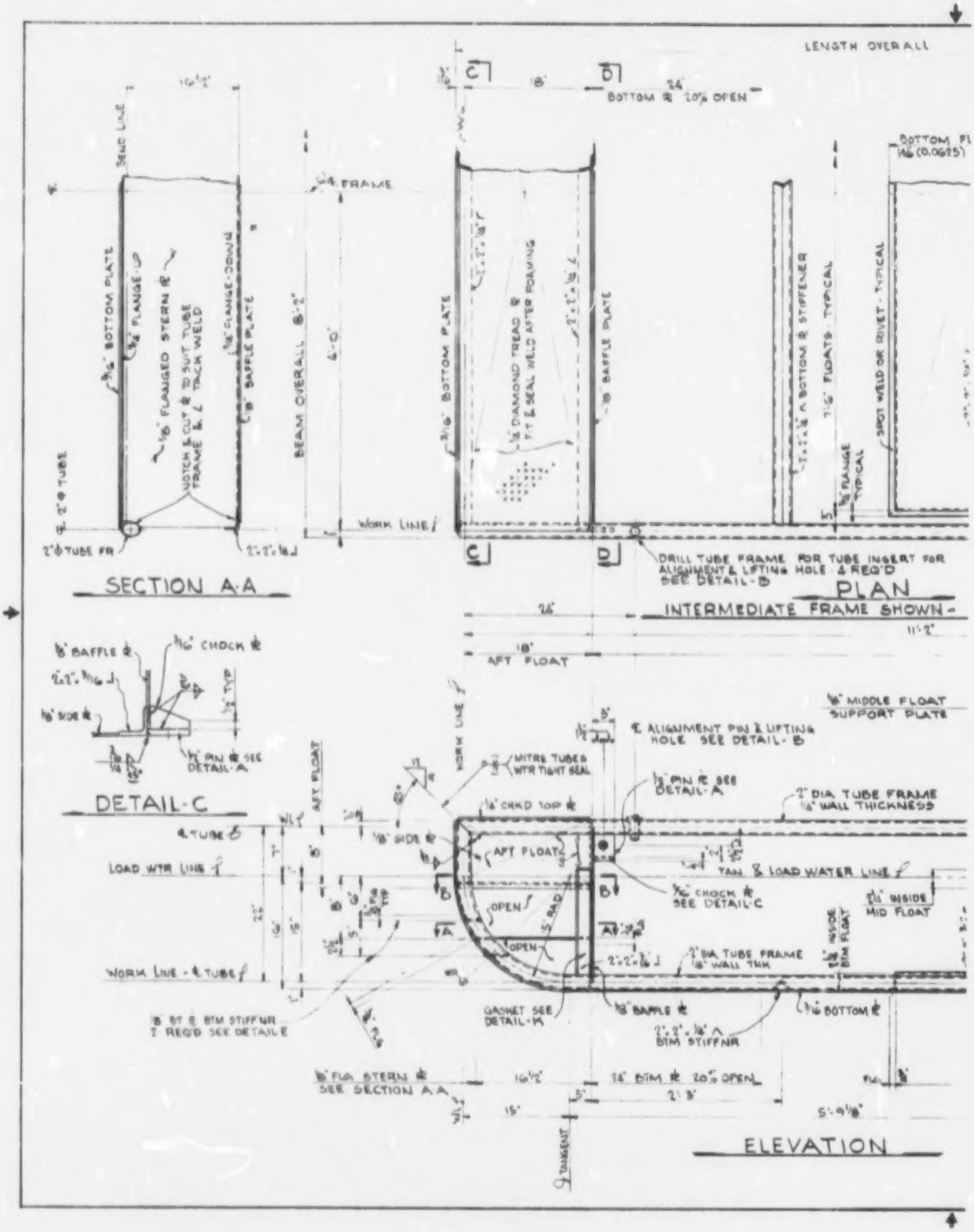


FIGURE 7 - PREDICTED PERFORMANCE OF HIGH-CURRENT BOOM WITH LESS THAN 10% OIL LOSS. BASED ON FULL SCALE TEST RESULTS (ρ_o = 0.89) AND FROUDE NUMBER SCALING FOR OTHER ρ_o'S


LENGTH OVERALL
SECTION A-A
DETAIL-C
PLAN
INTERMEDIATE FRAME SHOWN-
ELEVATION
BEAM OVERALL 8'-2"
WORK LINE
3/16" BOTTOM PLATE
1/8" BAFFLE PLATE
1/8" FLANGED STERN ℞
NOTCH & CUT ℞ TO SUIT TUBE FRAME & L TACK WELD
2" Φ TUBE FR
2"×2"×1/8" L
BOTTOM ℞ 20% OPEN
1/8" DIAMOND TREAD ℞ FIT & SEAL WELD AFTER FOAMING
DRILL TUBE FRAME FOR TUBE INSERT FOR ALIGNMENT & LIFTING HOLE 4 REQ'D SEE DETAIL-B
SPOT WELD OR RIVET - TYPICAL
7'-6" FLOATS TYPICAL
1/8" BAFFLE ℞
3/16" CHOCK ℞
1/8" SIDE ℞
1/2" PIN ℞ SEE DETAIL-A
AFT FLOAT
1/8" MIDDLE FLOAT SUPPORT PLATE
℄ ALIGNMENT PIN & LIFTING HOLE SEE DETAIL-B
MITRE TUBES WTR TIGHT SEAL
1/8" CHKD TOP ℞
2" DIA TUBE FRAME 1/8" WALL THICKNESS
TAN & LOAD WATER LINE
3/16" CHOCK ℞ SEE DETAIL-C
LOAD WTR LINE
WORK LINE - ℄ TUBE
OPEN
5' RAD
1/8" BAFFLE ℞
3/16" BOTTOM ℞
2"×2"×1/8" L BTM STIFFNR
GASKET SEE DETAIL-K
1/8" FLG STERN ℞ SEE SECTION A-A
24" BTM ℞ 20% OPEN
16 1/2"
15"
2'-3"
5'-9 1/8"
11'-2"
TANGENT

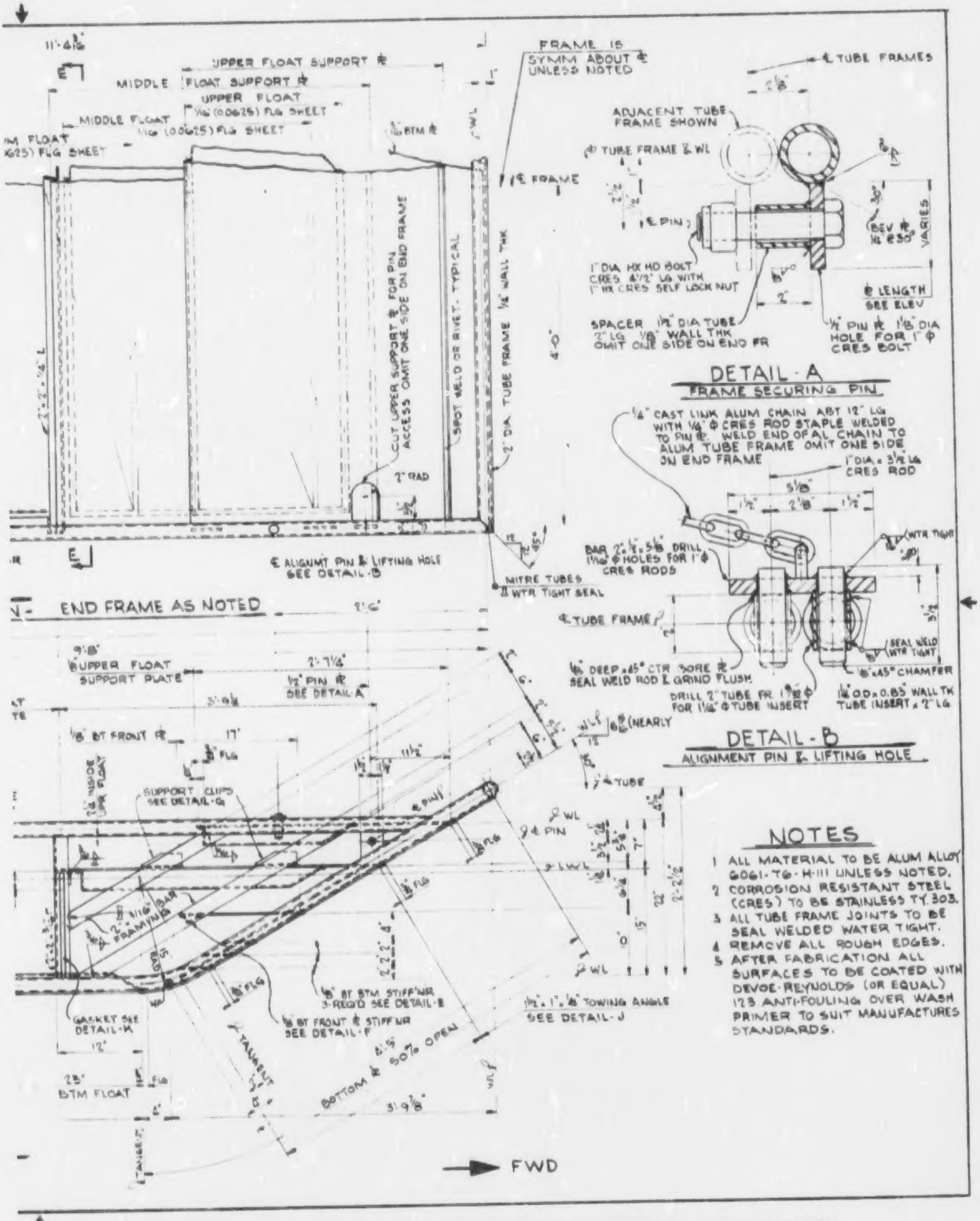
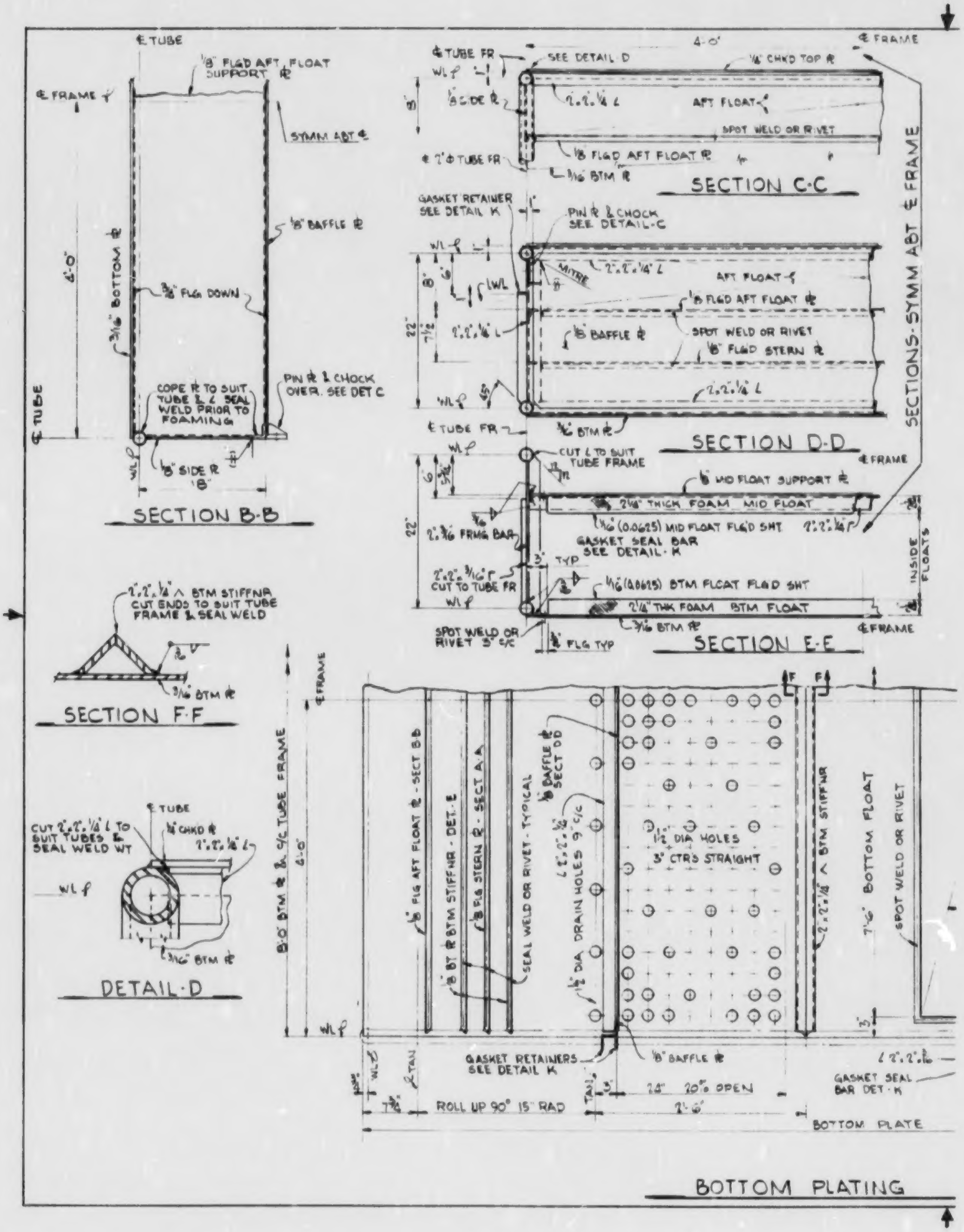
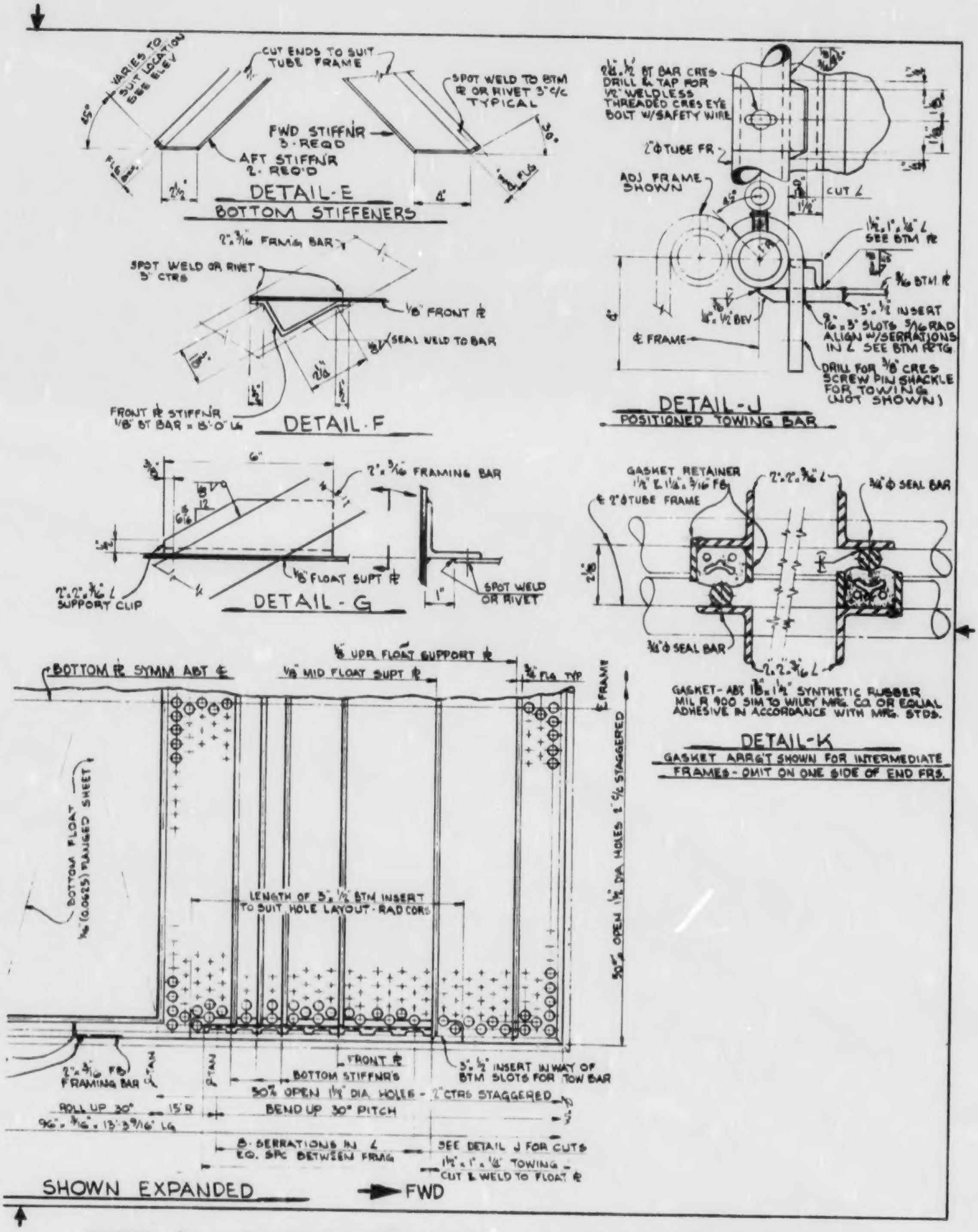

11'-4⅛"
UPPER FLOAT SUPPORT ℄
MIDDLE FLOAT SUPPORT ℄
UPPER FLOAT
1/16 (0.0625) FLG SHEET
MIDDLE FLOAT
1/16 (0.0625) FLG SHEET
BTM FLOAT
(0.0625) FLG SHEET
FRAME IS SYMM ABOUT ℄ UNLESS NOTED
℄ FRAME
CUT UPPER SUPPORT ℄ FOR PIN ACCESS OMIT ONE SIDE ON END FRAME
SPOT WELD OR RIVET - TYPICAL
2" DIA TUBE FRAME 1/8" WALL THK
2" RAD
℄ ALIGNMT PIN & LIFTING HOLE SEE DETAIL-B
MITRE TUBES & WTR TIGHT SEAL
END FRAME AS NOTED
℄ TUBE FRAMES
ADJACENT TUBE FRAME SHOWN
℄ TUBE FRAME & WL
℄ PIN
1" DIA HX HD BOLT CRES 4½" LG WITH 1" HX CRES SELF LOCK NUT
BEV ℄ ⅛ ∠30°
VARIES
℄ LENGTH SEE ELEV
SPACER 1½" DIA TUBE 2" LG 1/8" WALL THK OMIT ONE SIDE ON END FR
½" PIN ℄ 1⅛ DIA HOLE FOR 1" Φ CRES BOLT
DETAIL - A
FRAME SECURING PIN
¼" CAST LINK ALUM CHAIN ABT 12" LG WITH ¼" Φ CRES ROD STAPLE WELDED TO PIN ℄. WELD END OF AL CHAIN TO ALUM TUBE FRAME OMIT ONE SIDE ON END FRAME
1" DIA x 3½ LG CRES ROD
WTR TIGHT
BAR 2"x½"x5⅛ DRILL 1 1/16 Φ HOLES FOR 1" Φ CRES RODS
℄ TUBE FRAME
SEAL WELD WTR TIGHT
1/16 DEEP x 45° CTR BORE ℄ SEAL WELD ROD & GRIND FLUSH
1/16 x 45° CHAMFER
DRILL 2" TUBE FR. 1 7/16 Φ FOR 1¼ Φ TUBE INSERT
1¼ O.D. x 0.83 WALL TK TUBE INSERT x 2" LG
DETAIL - B
ALIGNMENT PIN & LIFTING HOLE
9'-8"
⅛ UPPER FLOAT SUPPORT PLATE
½" PIN ℄ SEE DETAIL-A
3'-9⅛
⅛ BT FRONT ℄
SUPPORT CLIPS SEE DETAIL-G
2"x3/16 FRAMING BAR
GASKET SEE DETAIL-K
⅛ BT BTM STIFF'NR 3-REQ'D SEE DETAIL-E
⅛ BT FRONT ℄ STIFF'NR SEE DETAIL-F
1½"x1"x⅛ TOWING ANGLE SEE DETAIL-J
BOTTOM ℄ 50% OPEN
TANGENT
23" BTM FLOAT
3'-9⅝
℄ WL
℄ PIN
℄ TUBE
FWD
NOTES
1 ALL MATERIAL TO BE ALUM ALLOY 6061-T6-H-111 UNLESS NOTED.
2 CORROSION RESISTANT STEEL (CRES) TO BE STAINLESS TY. 303.
3 ALL TUBE FRAME JOINTS TO BE SEAL WELDED WATER TIGHT.
4 REMOVE ALL ROUGH EDGES.
5 AFTER FABRICATION ALL SURFACES TO BE COATED WITH DEVOE-REYNOLDS (OR EQUAL) 123 ANTI-FOULING OVER WASH PRIMER TO SUIT MANUFACTURES STANDARDS.

FIGURE 6A - EPA HIGH-CURRENT BOOM - PLAN AND ELEVATION

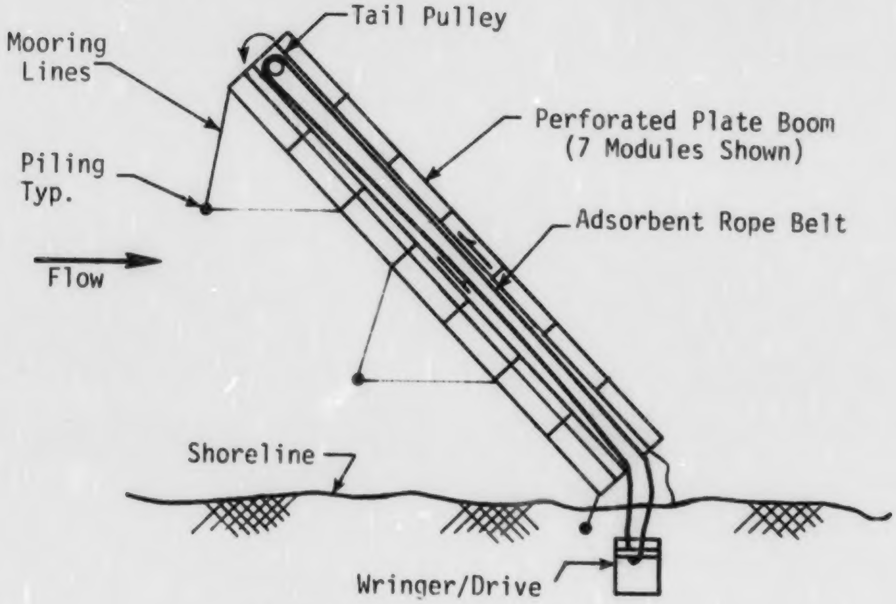

℄ TUBE
1/8" FLG'D AFT FLOAT SUPPORT ℞
℄ FRAME
SYMM ABT ℄
1/8" BAFFLE ℞
4'-0"
3/16" BOTTOM ℞
3/8" FLG DOWN
℄ TUBE
COPE ℞ TO SUIT TUBE & L SEAL WELD PRIOR TO FOAMING
PIN ℞ & CHOCK OVER. SEE DET C
WL
1/8" SIDE ℞
18"
SECTION B-B
℄ TUBE FR
SEE DETAIL D
4-0"
℄ FRAME
1/4" CHKD TOP ℞
WL
8"
1/8" SIDE ℞
2"×2"×1/4" L
AFT FLOAT ℄
SPOT WELD OR RIVET
1/8 FLG'D AFT FLOAT ℞
℄ 2" Φ TUBE FR
3/16 BTM ℞
SECTION C-C
GASKET RETAINER SEE DETAIL K
PIN ℞ & CHOCK SEE DETAIL-C
WL
MITRE
2"×2"×1/4" L
AFT FLOAT ℄
8"
6"
LWL
1/8 FLG'D AFT FLOAT ℞
22"
7 1/2
2"×2"×1/4" L
1/8" BAFFLE ℞
SPOT WELD OR RIVET
1/8" FLG'D STERN ℞
2"×2"×1/4" L
WL
3/16" BTM ℞
℄ TUBE FR
SECTION D-D
SECTIONS SYMM ABT ℄ FRAME
WL
CUT L TO SUIT TUBE FRAME
℄ FRAME
1/8" MID FLOAT SUPPORT ℞
2 1/4" THICK FOAM MID FLOAT
1/16" (0.0625) MID FLOAT FLG'D SHT
2"×2"×1/4" L
22"
2"×3/16 FRMG BAR
GASKET SEAL BAR SEE DETAIL K
3" TYP
2"×2"×3/16" L CUT TO TUBE FR
1/16 (0.0625) BTM FLOAT FLG'D SHT
INSIDE FLOATS
WL
2 1/4" THK FOAM BTM FLOAT
SPOT WELD OR RIVET 3" c/c
3/16 BTM ℞
3/4" FLG TYP
℄ FRAME
SECTION E-E
2"×2"×1/4" ∧ BTM STIFFNR CUT ENDS TO SUIT TUBE FRAME & SEAL WELD
3/16 BTM ℞
SECTION F-F
℄ TUBE
CUT 2"×2"×1/4" L TO SUIT TUBES & SEAL WELD WT
1/4" CHKD ℞
2"×2"×1/4" L
WL
3/16" BTM ℞
DETAIL-D
℄ FRAME
8'-0" BTM ℞ & C/C TUBE FRAME
4'-0"
1/8" FLG AFT FLOAT ℞ - SECT B-B
1/8" BT ℞ BTM STIFFNR - DET. E
1/8" FLG STERN ℞ - SECT A-A
SEAL WELD OR RIVET - TYPICAL
1/8" BAFFLE ℞ SECT DD
L 2"×2"×1/4"
1 1/2" DIA DRAIN HOLES 9" c/c
1 1/2" DIA HOLES
3" CTRS STRAIGHT
F
F
2"×2"×1/4" ∧ BTM STIFFNR
7'-6" BOTTOM FLOAT
SPOT WELD OR RIVET
3"
WL
GASKET RETAINERS SEE DETAIL K
1/8" BAFFLE ℞
L 2"×2"×3/16
GASKET SEAL BAR DET K
TAN
TAN
7 3/4"
ROLL UP 90° 15" RAD
3"
24"
20% OPEN
2'-6"
BOTTOM PLATE
BOTTOM PLATING



VARIES TO SUIT LOCATION SEE ELEV
45°
FLG
CUT ENDS TO SUIT TUBE FRAME
SPOT WELD TO BTM ⅊ OR RIVET 3" c/c TYPICAL
FWD STIFFNR 3-REQD
AFT STIFFNR 2-REQ'D
30°
FLG
2½"
4"
DETAIL-E
BOTTOM STIFFENERS
2" x 3/16 FRMG BAR
SPOT WELD OR RIVET 3" CTRS
1/8" FRONT ⅊
SEAL WELD TO BAR
FRONT ⅊ STIFFNR 1/8" BT BAR x 13'-0" LG
DETAIL-F
6"
2" x 3/16 FRAMING BAR
2" x 2" x 3/16 L SUPPORT CLIP
1/8" FLOAT SUPT ⅊
1"
SPOT WELD OR RIVET
DETAIL-G
2¼ x ½ BT BAR CRES DRILL & TAP FOR ½" WELDLESS THREADED CRES EYE BOLT W/SAFETY WIRE
2" Φ TUBE FR
ADJ FRAME SHOWN
CUT L
1½"
1½ x 1 x 1/8 L SEE BTM ⅊
3/16 BTM ⅊
3" x ½ INSERT
¼" x ½" BEV
℄ FRAME
9/16 x 3" SLOTS 5/16 RAD ALIGN W/SERRATIONS IN L SEE BTM FRTG
DRILL FOR 3/8" CRES SCREW PIN SHACKLE FOR TOWING (NOT SHOWN)
DETAIL-J
POSITIONED TOWING BAR
GASKET RETAINER 1½" x 1¼ x 3/16 FB
2" x 2" x 3/16" L
¾" Φ SEAL BAR
℄ 2" Φ TUBE FRAME
2⅜
¾" Φ SEAL BAR
2" x 2" x 3/16 L
GASKET - ABT ¾" x 1½" SYNTHETIC RUBBER MIL R 900 SIM TO WILEY MFG. CO OR EQUAL ADHESIVE IN ACCORDANCE WITH MFG. STDS.
DETAIL-K
GASKET ARRG'T SHOWN FOR INTERMEDIATE FRAMES - OMIT ON ONE SIDE OF END FRS.
1/8" UPR FLOAT SUPPORT ⅊
BOTTOM ⅊ SYMM ABT ℄
1/8" MID FLOAT SUPT ⅊
¾" FLG TYP
℄ FRAME
BOTTOM FLOAT 1/16" (0.0625) FLANGED SHEET
LENGTH OF 3" x ½ BTM INSERT TO SUIT HOLE LAYOUT - RAD CORS
50% OPEN 1½" DIA HOLES 2" c/c STAGGERED
FRONT ⅊
2" x 3/16 FB FRAMING BAR
BOTTOM STIFFNR'S
3" x ½" INSERT IN WAY OF BTM SLOTS FOR TOW BAR
50% OPEN 1½" DIA HOLES - 2" CTRS STAGGERED
ROLL UP 30°
15 R
BEND UP 30° PITCH
96" x 3/16" x 13'-3 9/16" LG
8-SERRATIONS IN L EQ. SPC BETWEEN FRMG
SEE DETAIL J FOR CUTS
1½" x 1" x 1/8" TOWING - CUT & WELD TO FLOAT ⅊
SHOWN EXPANDED
FWD

FIGURE 6B - EPA HIGH-CURRENT BOOM - BOTTOM PLATE AND DETAILS

NOTE: Figure 7 on page 11.


Tail Pulley
Mooring Lines
Perforated Plate Boom (7 Modules Shown)
Piling Typ.
Adsorbent Rope Belt
Flow
Shoreline
Wringer/Drive

Adsorbent Rope Belt Skimmer

FIGURE 8 - EXAMPLE OF MEANS TO RECOVER OIL

APPLICATIONS

Diversionary Boom. This most obvious application for the high-current boom is downstream from oil loading/unloading docks. Figure 9 shows a typical permanent installation of this type. The design of the boom installation near a shoreline will differ depending on the shoreline topography and other considerations. It is essential, however, that skimmers be available to rapidly recover oil as it is diverted shoreward. The mooring system design should include a power winch to allow easy opening of the boom to free debris accumulations. The design should also include "weak links" in the moorings to allow the boom to break free and string downstream in the event of excessive flood water currents or collisions with large floating objects.

Boom modules are also designed for truck transport to a spill location and the joining process is quick and simple, permitting their use on an ad hoc basis in a spill emergency.

Emergency Self-Propelled Skimmer. Another useful application of the high-current boom design is to make a skimmer from an ordinary work vessel or fishing vessel in an emergency. A configureation of this type is sketched in Figure 10. Of course adaptive elements are required in attaching the boom to the vessel of convenience. Truck transport of boom modules for this purpose is warranted by the predicted performance.

Inshore Skimmer. If supported by a vessel having a "U" shaped bow, or by a very small and shallow draft barge, module(s) can be used as a sweep skimming device for inshore waters. Two possible configurations are shown in Figures 11a and 11b.

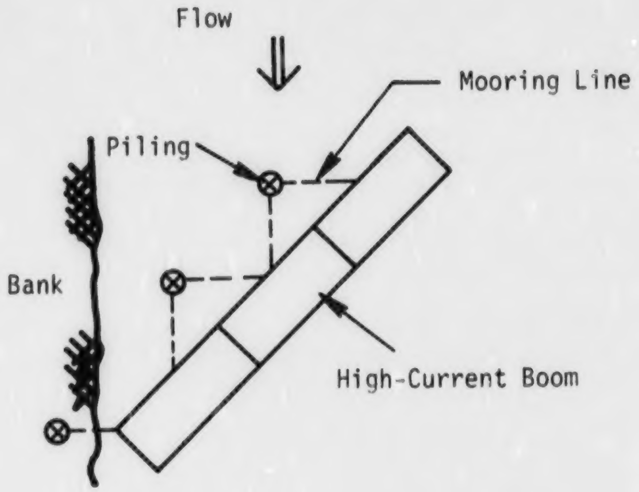

Flow
Mooring Line
Piling
Bank
High-Current Boom

FIGURE 9 - PLAN VIEW OF HIGH-CURRENT BOOM IN DIVERSIONARY CONFIGURATION

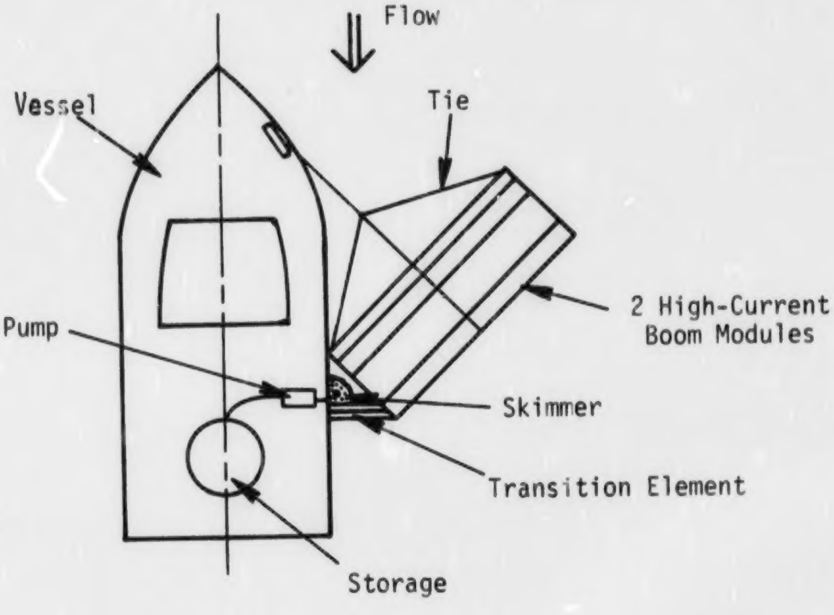
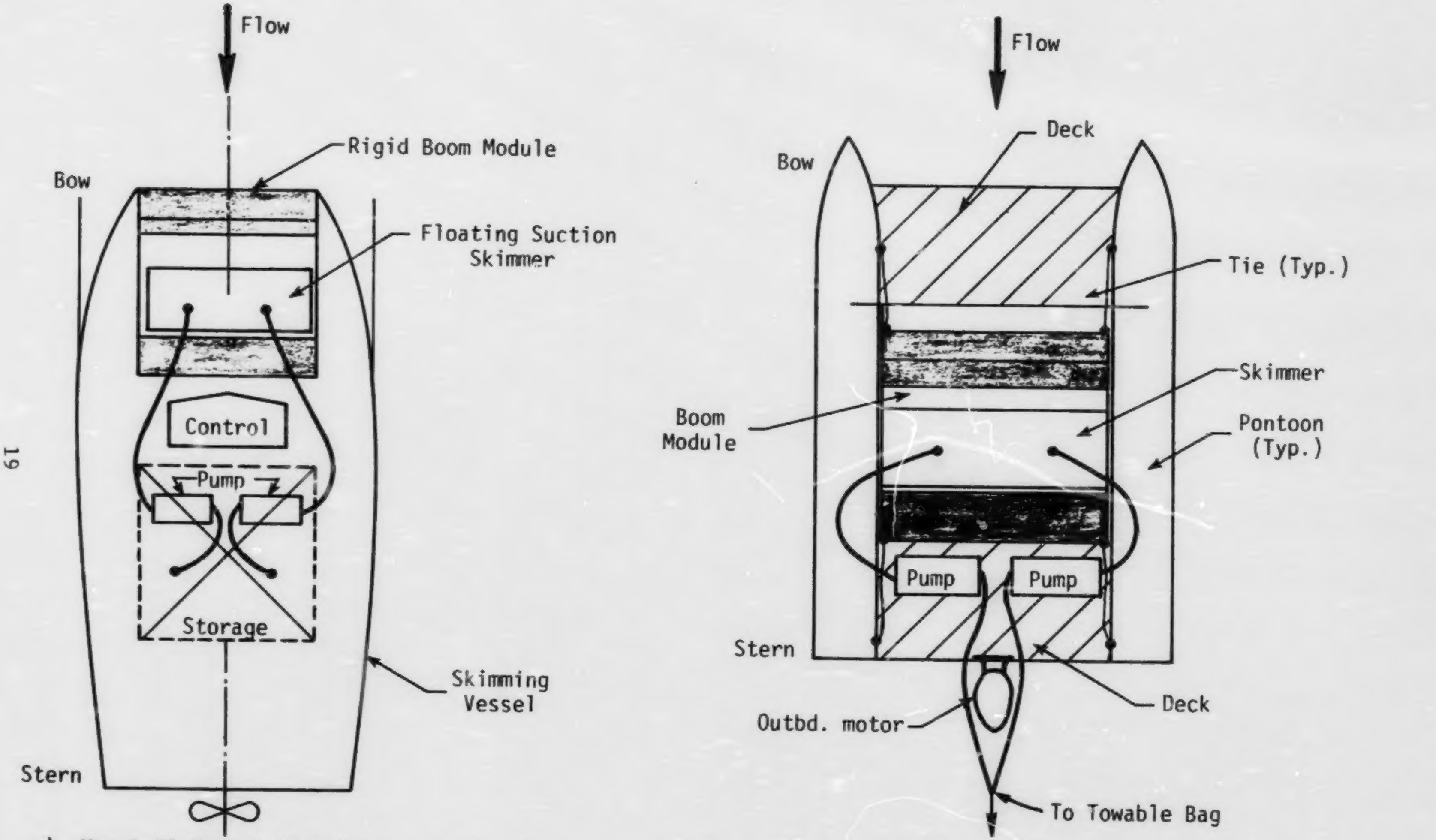

Flow
Vessel
Tie
2 High-Current Boom Modules
Pump
Skimmer
Transition Element
Storage

FIGURE 10 - EMERGENCY SELF-PROPELLED SKIMMER USING RIGID, PERFORATED-PLATE BOOM MODULES


Flow
Rigid Boom Module
Bow
Floating Suction Skimmer
Control
Pump
Storage
Skimming Vessel
Stern
Flow
Deck
Bow
Tie (Typ.)
Skimmer
Boom Module
Pontoon (Typ.)
Pump
Pump
Stern
Deck
Outbd. motor
To Towable Bag

a) Monohull Vessel With Permanent Storage

b) Catamaran Vessel With Towable Bag Storage

FIGURE 11 - TWO PERMANENT SKIMMER CONFIGURATIONS USING RIGID BOOM MODULES

V. DISCUSSION OF THE PROBLEM

THE PROBLEM

Historically and presently the most effective way of controlling the movement of oil spilled on water is to use floating oil barriers. At present there are over 80 different commercailly available oil spill barriers, or booms. In recent years significant improvements have been made in the basic oil boom design: They include increasing the boom freeboard to minimize oil splashover in waves, enhancing boom flexibility to allow wave compliance, improving boom strength and stability in currents and making design changes to facilitate handling, deployment, cleaning and storing.

In spite of these improvements in design, however, a fundamental problem remains in controlling oil with booms in high currents and in steep waves. This report considers the problem of oil spill control on fast-moving waters as found in rivers and tidal estuaries. The problem of oil booms in waves is equally challenging, but one must understand the separate effects of currents and waves in order to understand their complex interaction.

Analysis of possible clean-up techniques applicable to an oil spill on fast moving waters makes it clear that the response time is critical. Response time is measured from the time a spill is reported to the time clean-up equipment is mobilized and working. If a spill occurs on a river where the current is 3 knots (See English-Metric Conversion Table, Appendix G), for instance, the oil lens centroid would be approximately 1.7 miles downstream in 30 minutes, neglecting the effects of wind and spreading. Use of oil booms for this situation would be limited to the following cases:

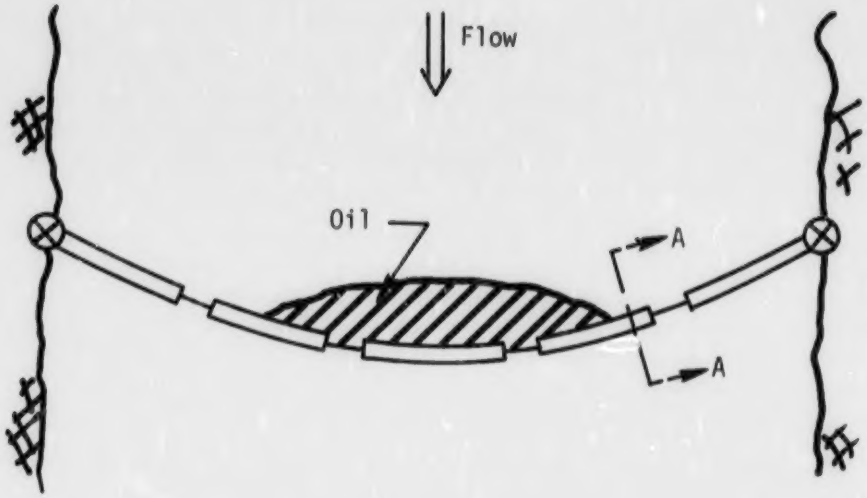
(1) Durable permanently-deployed floating booms.

(2) Stored booms ready for immediate deployment at a location downstream within response constraints.

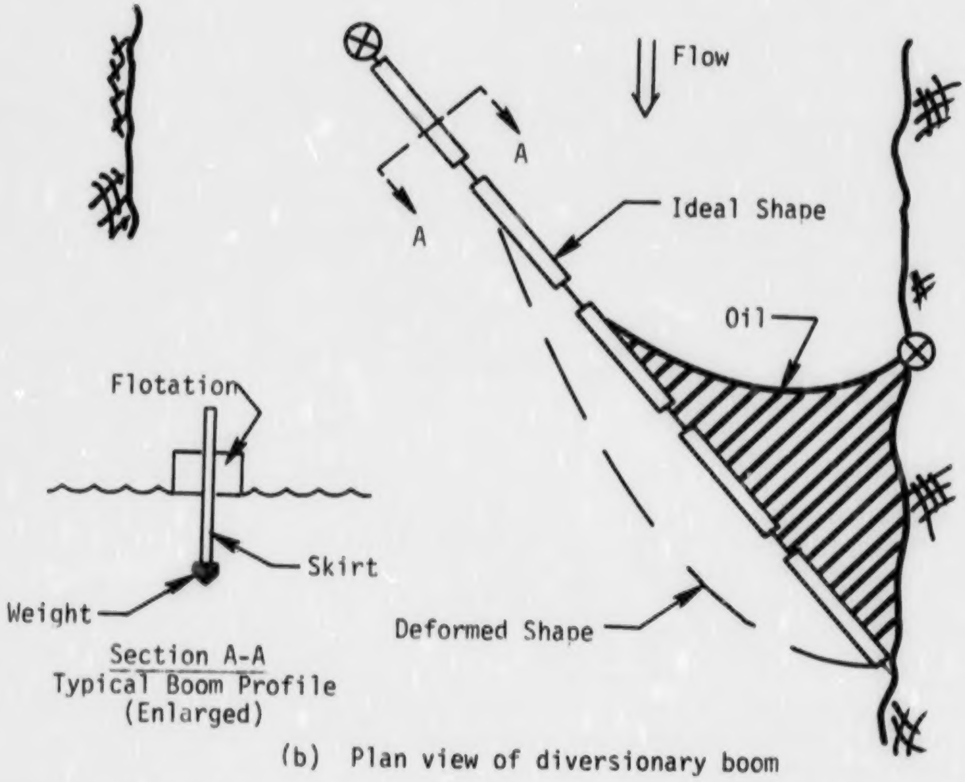
(3) Completely portable boom systems capable of being rapidly transported and deployed at any location.

In most cases it is important to immediately remove oil temporarily contained or diverted by a boom, because oil can be lost by droplet formation [escaping at current velocities as low as 0.7 knots (2)].

A containment boom is normally fixed at each end and the elongated barrier is allowed to drape in a U-shaped catenary because of current drag forces. Such a boom configuration is shown in Figure 12a. Oil drifting toward a boom, if retained, will thicken locally in front of the boom (set-up), making oil removal feasible. Shell tests (2) have shown that booms of



(a) Plan view of containment boom


Flow
A
A
Ideal Shape
Oil
Flotation
Skirt
Weight
Deformed Shape
Section A-A
Typical Boom Profile
(Enlarged)

(b) Plan view of diversionary boom

FIGURE 12 - CONTAINMENT AND DIVERSION IN RIVER CURRENTS

usual dimensions can allow oil to escape at velocities as low as 0.7 knots, although under certain conditions oil containment at velocites up to 1.5 knots has been achieved.

A large number of experiments (3,4) directed toward understanding the various mechanisms of oil failure under a containment boom have generally revealed that containment is feasible with shallow to moderate draft conventional booms in currents up to 1.5 knots.

One generally accepted analysis (3) of "drawdown" oil losses under a containment boom indicates that in a 2-1/2 knot current, skirt drafts of 4 to 10 feet are needed for oils having specific gravities of 0.85 to 0.95. Since drag forces increase as the square of the velocity and linearly with increased draft, the structural strength and stability of a boom in fast-moving waters is also of major concern. We conclude that high-current containment using deep-draft booms is not a viable approach to the problem.

A diversionary boom is moored at an acute angle to the river flow and shunts oil from the high velocity flow region in the middle to the slower region near the bank (Figure 12b). The diversionary boom shape has been found in practice to keep oil from escaping downstream in higher currents than the containment boom shape. A diversionary boom, however, is difficult to moor such that every segment of the boom makes the same acute angle with the flow vector (to afford maximum oil retention). The natural tendency of the boom is to deform under flow forces as indicated by the dashed line in Figure 10b. When any portion of the boom is nearly normal to the flow, containment boom losses can occur. Thus diversion, usually with shallower conventional booms, offers more promise than containment. But even diversion can be inadequate in moderately high currents. A more complete discussion of diversion and containment is contained in the next part of Section V.

Many of our rivers and tidal estuaries have currents in excess of two knots. Since mere design changes of the conventional boom do not hold prospect for fast-moving waters, a radically different concept is appropriate. Our approach is to improve upon the conventional boom profile by adding a baffle immediately upstream of a boom to slow down the surface flow. Based on test results such a baffle/boom combination - an unconventional boom profile - offers effective oil control in higher currents in both containment and diversion applications.

LIMITATIONS OF CONVENTIONAL BOOMS

A conventional boom is shown in Figure 13, as it was used in an oil spill. The components of a typical boom are sketched in Section A-A of Figure 12. Although there are differences in the way they are moored, i.e., bottom-tensioned, top-tensioned, or skirt-tensioned, the loss of oil in each case is generally determined by the effective boom draft when current forces are acting (and not the still-water draft). The following is a discussion of the mechanisms of oil loss for booms used in both containment and diversion. The normally reported profile of oil accumulated against a barrier is that for a large contained volume as shown in Figure 14a. Possible failure mechanisms are entrainment near the headwave (shown) and drawdown near the barrier. Our specific interest is in small contained volumes because in high currents - the major concern of this program - rapid, simultaneous oil recovery is essential.

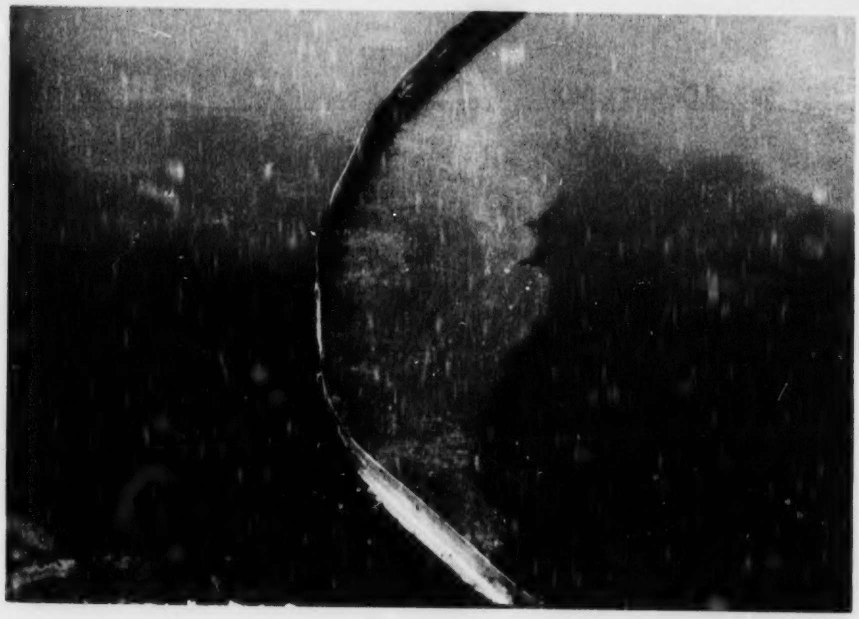


FIGURE 13 - CONVENTIONAL BOOM CONTAINING SPILLED OIL

Figure 12a shows a typical oil boom placed across a river in the containment configuration. Provided that the set-up oil volume is small (slick length ≤ 5 times the boom draft), oil loss under a boom is skirt draft sensitive and can be described by the densimetric Froude number:

$$F_d = V/(g\Delta h)^{1/2} \tag{1}$$

where

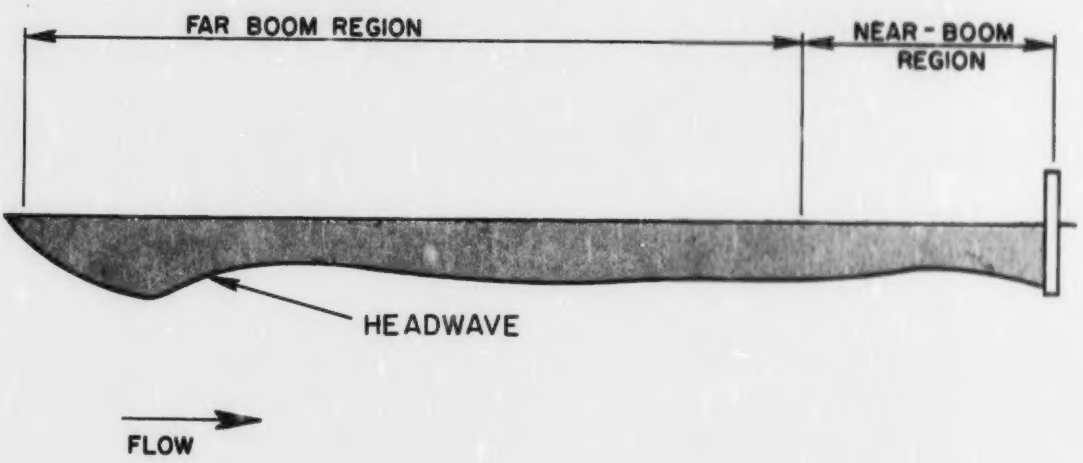
V = Free-stream velocity
g = Acceleration of gravity
Δ = Fractional density difference,
$(\rho_w - \rho_o)/\rho_w$
(ρ_w = water density, ρ_o = oil density)
h = Barrier draft

Recent Shell tests indicate that the inception of "near-boom" oil loss, as shown in Figure 14b, occurs when

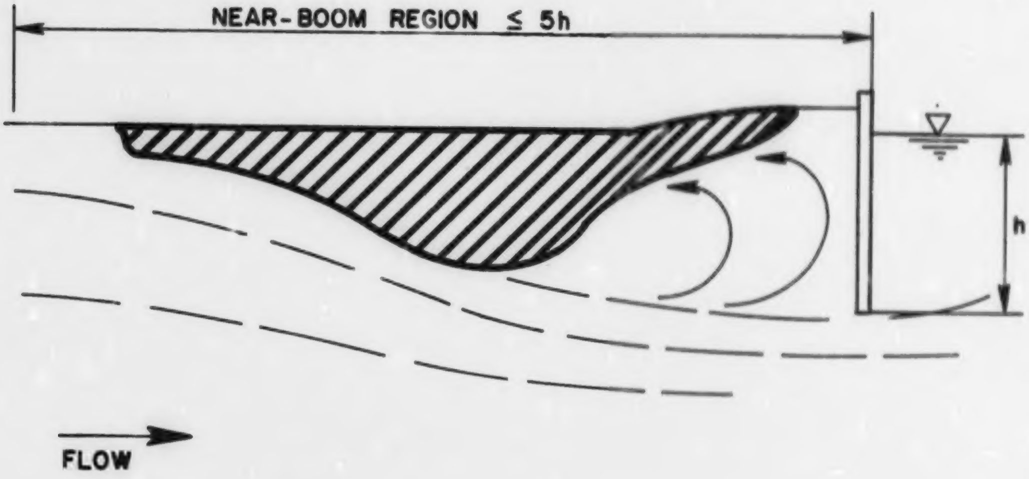
$$F_d \doteq 1 \tag{2}$$

Previously (2) such losses were thought to be independent of skirt draft.

A physical explanation for this failure mode follows: If the contained oil volume is small, it will accumulate in the wedge of water in front of the


FAR BOOM REGION
NEAR-BOOM REGION
HEADWAVE
FLOW

(a) LARGE VOLUME OIL SET-UP


NEAR-BOOM REGION ≤ 5h
h
FLOW

(b) SMALL VOLUME OIL SET-UP

FIGURE 14 - OIL SET-UP IN FRONT OF A BARRIER IN A TWO DIMENSIONAL CURRENT FIELD

boom (see Figure 14b). In this way the set-up lens is protected from the high-velocity streamlines associated with water flow under the boom. There is sufficient suction when $F_d = 1$, however, to allow oil to draw down under a boom. Figure 15 contains curves for the minimum boom draft requirement for small-volume containment as a function of free-stream current and oil specific gravity using a 1.0 Froude number.

A second oil loss mechanism associated with droplet formation at the headwave is called "entrainment"*. This loss generally occurs in containment with larger contained oil volumes at about 1 knot. As discussed below, the entrainment mechanism is the probable cause of diversionary losses at moderate currents. Wicks (2) suggested that droplets will form when the Weber number based on oil droplet diameter exceeds 22, i.e.,

$$(We)_{cr} = \frac{\rho_w V^2_{cr} d_o}{\sigma_{ow} g} > 22 \tag{3}$$

where

V_{cr} = Critical velocity

d_o = Maximum oil droplet diameter

σ_{ow} = Oil/water interfacial tension

and other symbols are described previously. Wicks (2) further suggests that the maximum droplet diameter is given by

$$d_o = \pi \left(\frac{\sigma_{ow}}{\rho_w - \rho_o} \right)^{1/2} \tag{4}$$

Since very few droplets of maximum size are likely to occur, the question is: "What is the most probable average droplet diameter associated with the inception of measurable losses?"

Both tests and field experience have suggested that a velocity of 1 knot is large enough to cause diesel oil loss by entrainment. The sudden failure which occurs with large contained volumes at currents in excess of 1 knot is illustrated by data in Figure 16 from offshore oil boom tests by the U. S. Coast Guard. (5) The test oil in this case was soybean oil.

One can estimate the effective droplet diameter consistent with Equations (3) and (4) by assuming for light oils such as diesel fuel oil in fresh water:

---

* In this duscussion "drawdown" implies oil losses are sensitive to skirt draft and thus dependent on the densimetric Froude number. "Entrainment" implies no skirt draft dependence and is governed by the Weber number. Both types of losses look like droplet failure.

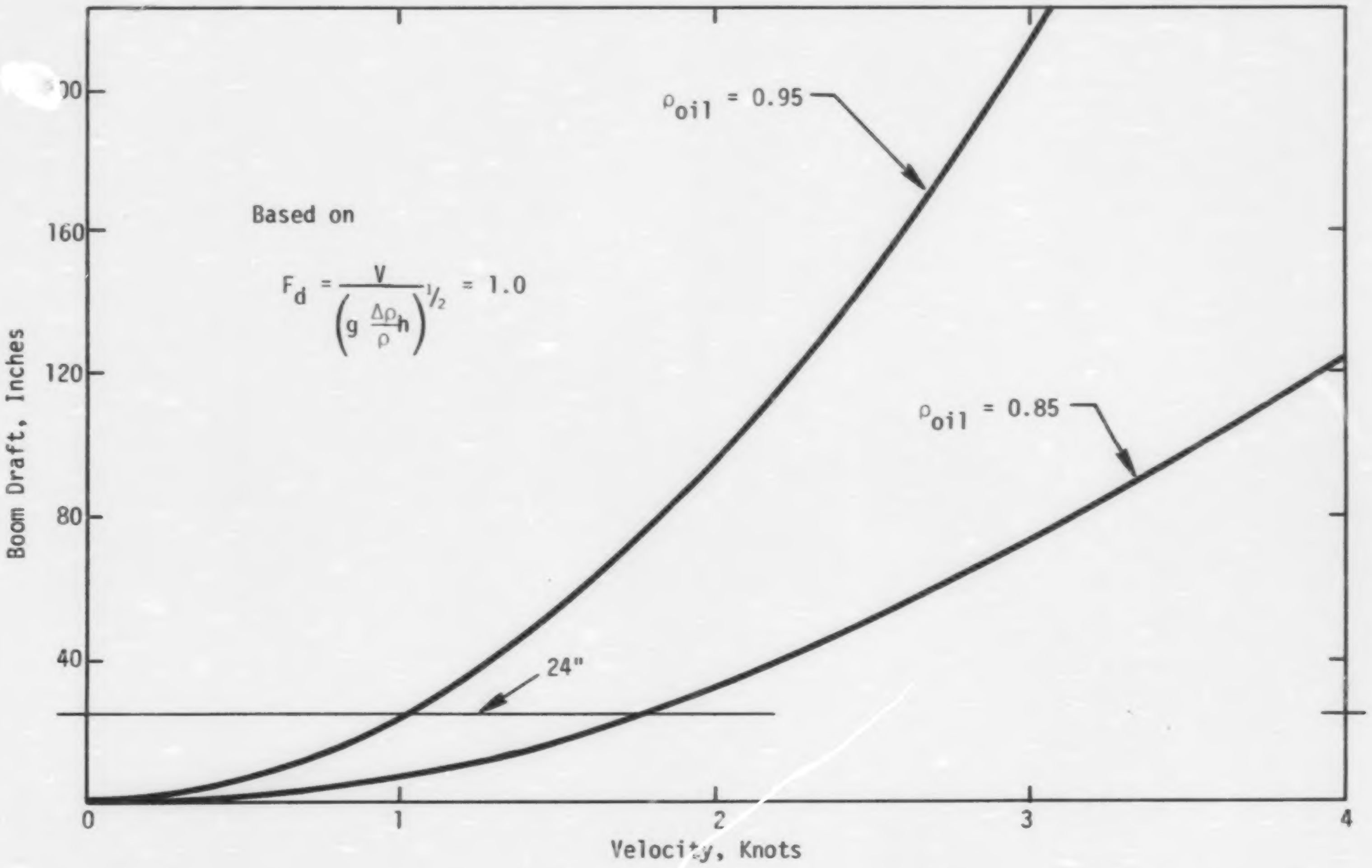


FIGURE 15 - MINIMUM BOOM SKIRT DRAFT FOR CONTAINMENT

V_{cr} = 1 knot = 1.69 fps

σ_{ow} = 30 dyne/cm = .0021 lb/ft

ρ_o = 0.85 g/cc = 53.07 lb/ft^3

ρ_w = 1.0 g/cc = 62.43 lb/ft^3

g = 32.2 ft/sec^3

Using Equation (3)

$$d_{eff} = \frac{22\ \sigma_{ow}\ g}{\rho_w\ V^2{}_{cr}} = 0.0083 \text{ ft or } 0.1 \text{ inch}$$

And from Equation (4)

$$d_o = 0.565 \text{ inch}$$

Thus

$$\frac{d_{eff}}{d_o} = 0.18 \tag{5}$$

If we further assume that Equation (5) is approximately true for all oils, then the conditions for entrainment failure are quantifiable.

A diversion boom placed to divert oil to shore in a river was shown previously in Figure 12b. Because test results suggest that deep-draft booms do not divert oil better than shallower ones, we suspect entrainment to be the governing failure mechanism in diversion.

The only required modification to Equations (3) - (5) is to substitute the normal (to the boom) component of the free-stream velocity for the free-stream velocity. Then, for diversion

$$V^2{}_{cr} = \frac{22\ \sigma_{ow}\ g}{\rho_w\ d_{eff}\ \text{Cos}^2\theta} \tag{6}$$

and, as before

$$d_{eff} = 0.56\left(\frac{\sigma_{ow}}{\rho_w - \rho_o}\right)^{1/2} \tag{7}$$

The predictions of Equations (6) and (7) are plotted in Figure 17 as a function of diversionary angle. For a No. 2 Fuel Oil spill, for instance, a conventional boom - if stable and carefully moored - will successfully divert oil at a diversionary angle of 60° in currents up to 1.5 knots.

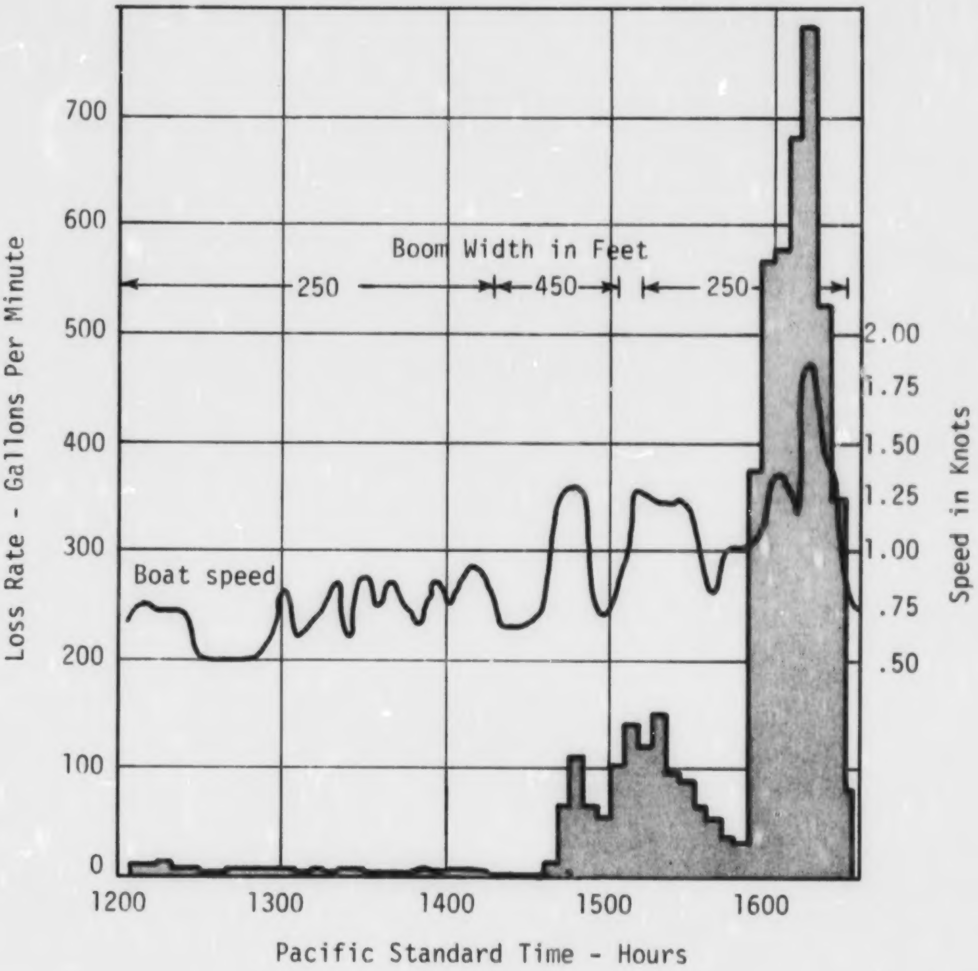


FIGURE 16 - HISTOGRAM OF OIL LOSS FROM COAST GUARD BOOM TOW TESTS (FROM REFERENCE 11)

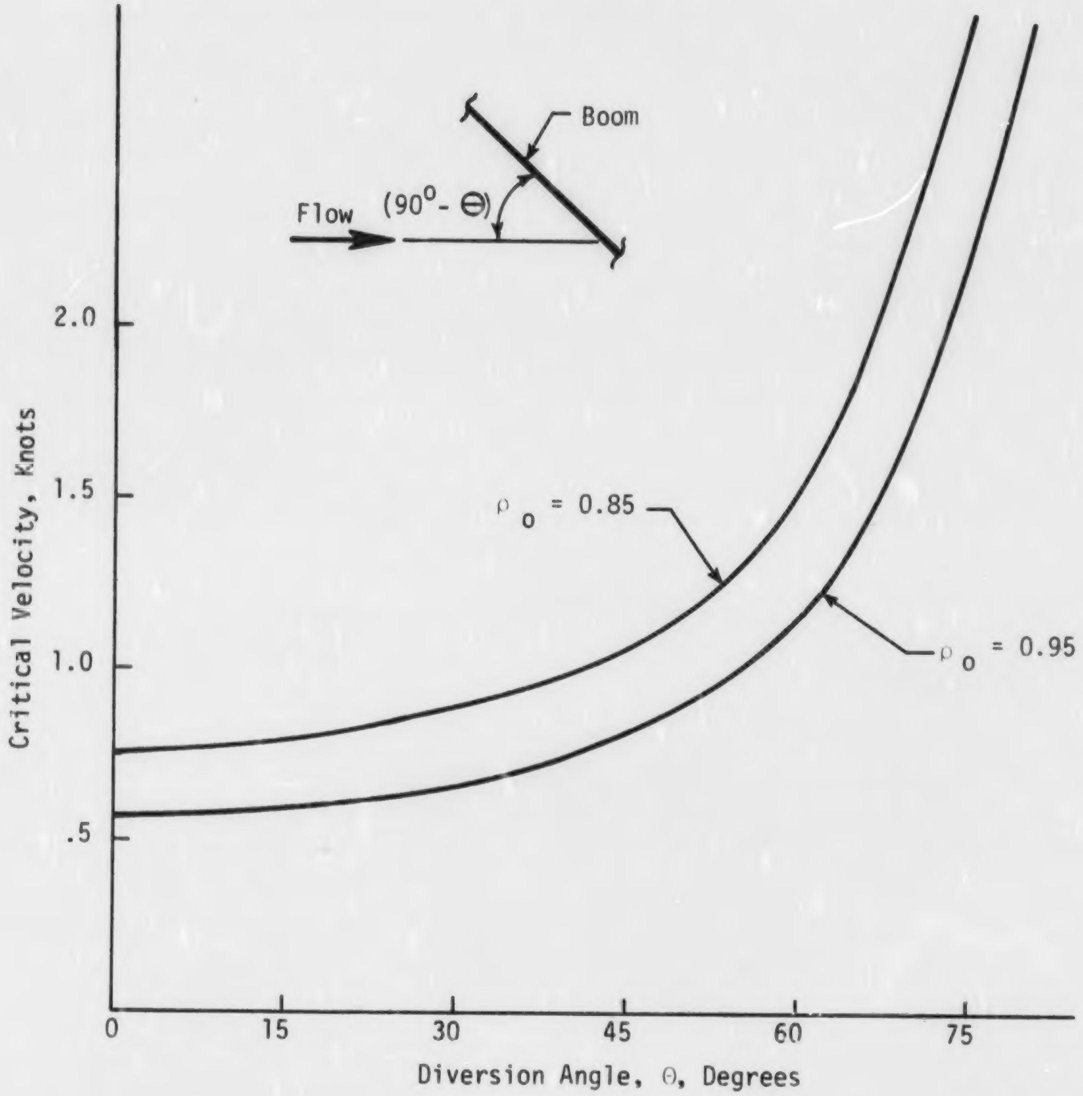


FIGURE 17 - CRITICAL VELOCITY FOR OIL LOSS IN DIVERSION

PREVIOUS SHELL INVESTIGATIONS

Late in 1969 Shell found means for containing oil at a current velocity in excess of that found for conventional booms (Figure 18). The technique used was to alter the near-boom region (compare with Figure 14b) to prevent premature oil drawdown when small oil quantities are set up. The boom section tested in 1969 could be considered a special case of a general means for creating a quiescent pond by diffusing the fluid flow. This was accomplished by placing baffles (the vertical net and the horizontal lower perforated membrane in Figure 18) in front of a conventional barrier. The downstream length-to-draft ratio of the profile tested in our laboratory current tank is 4.5, meaning that the upstream face is close to the streamline separation point for a conventional barrier in potential flow. We found that:

1. When small quantities of oil were placed between the upstream and downstream floats, the critical velocity was increased from 0.7 knots for a conventional barrier to 1.4 knots for the test profile--a two-fold increase in containment velocity.
2. When oil was placed upstream of the boom profile the oil entered the upstream net. But upon passing through the net, the oil lens broke into many small droplets. The entrained droplets were then lost through the bottom membrane at velocities between 0.7 and 1.4 knots.

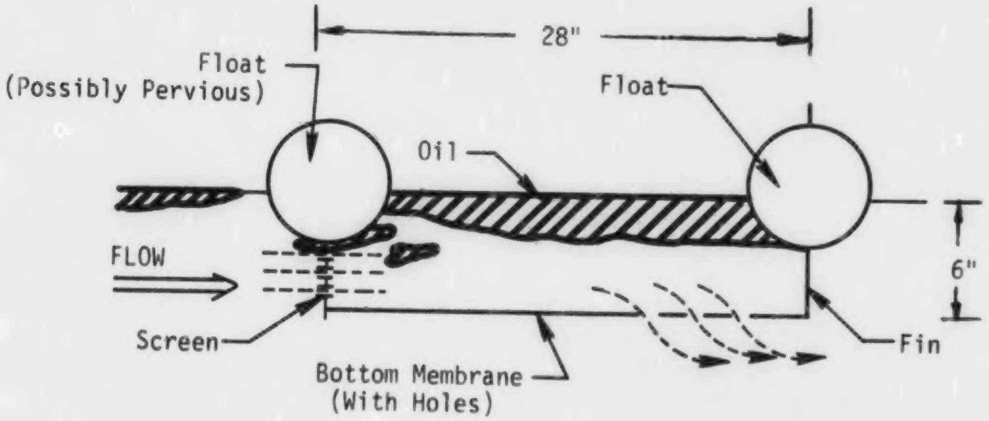


FIGURE 18 - FIRST HIGH-CURRENT BOOM MODEL BY SHELL

The conclusion drawn from the exploratory tests is that although the unconventional profile had the capability of doubling the containment capacity of a conventional boom, an alternative to the forward net baffle must be found to overcome the oil entrainment problem.

The basic principle of artificially creating a quiescent pond to allow oil to set up in a relatively thick lens is generally accepted today as a valid technique.

Recognizing that the fundamental process involved in creating an artificial quiescent pond is flow diffusion and that the forward oil entry region must be a relatively open configuration, a suitable alternative was devised. In further tests of the flow diffusion principle a forward baffle was formed using a bundle of short parallel tubes (with center-lines parallel to the flow vector) and a lower submerged baffle to replace the previous net and by using an open-bottomed "Coke box" grid to replace the lower porous membrane. The revised test section, shown in Figure 19, was found to eliminate oil entrainment problems observed in tests of the earlier model using a net.

As seen in Figure 19 the improved boom profile has a more lengthy upstream to downstream "boom profile" dimension than a conventional boom, somewhat like a skimmer. The flow diffusion principle, of course, is also applicable to skimmer configurations. Since it would be quite difficult to develop a flexible elongate boom with such a complicated cross-section, in earlier development programs we decided to change the original boom concept into a flow-diffusing baffle system for a sweep-type oil skimmer. Early in 1972 a prototype inshore sweep skimming system incorporating flow diffusing baffles was designed and fabricated (1). Investigations revealed that flow diffusing baffles could be thought of as flow energy absorbing baffles, the idea being to extract the maximum flow energy from the relative water velocity while at the same time endeavoring to minimize oil entrainment caused by excessive turbulence. The baffle systems used in developing the skimmer were incorporated directly, without attempting to optimize the configuration.

This report describes using flow-diffusing techniques to design a high-current boom.

INVESTIGATIONS OF OTHERS

Early in 1970 the Garrett Corporation (6) conducted tests on a "quiescent pond" baffle arrangement for use in a proposed skimmer arrangement for use in the API-sponsored Sea Dragon offshore skimming system. The baffle system that Garrett tested as a skimmer can be equally considered as a two-dimensional unconventional boom profile. Figure 20 shows one configuration applicable to a boom design that they evaluated. It includes a forward spillway and bottom louvers. Garrett model tests proved that the combined forward and submerged lower baffle systems of their design were essential to the effectiveness of the quiescent pond. They did not, however, have an effective forward baffle arrangement for minimizing bow turbulence effects in waves.

Early in 1971, Atlantic Research Corporation (3) found that a bottomless double boom arrangement had greater velocity capability for oil retention than that of a conventional boom. Their investigations revealed that the profile shown in Figure 21 had a 25% increase in containment capability over that of a conventional barrier. Important test results are that the forward barrier must be hydrodynamically shaped to reduce entrainment effects but that a flat-plate aft barrier is adequate.

In late 1971, Ocean Systems, Inc. (7) tested the unconventional boom configuration shown in Figure 22. The "dynamic keel" 1/3-scale version, having a width of 2-1/3 feet and a draft of 10 inches, had an oil loss rate of 9% at 0.9 fps (based on the volume of oil applied) and 52.5% at 1.5 fps. This

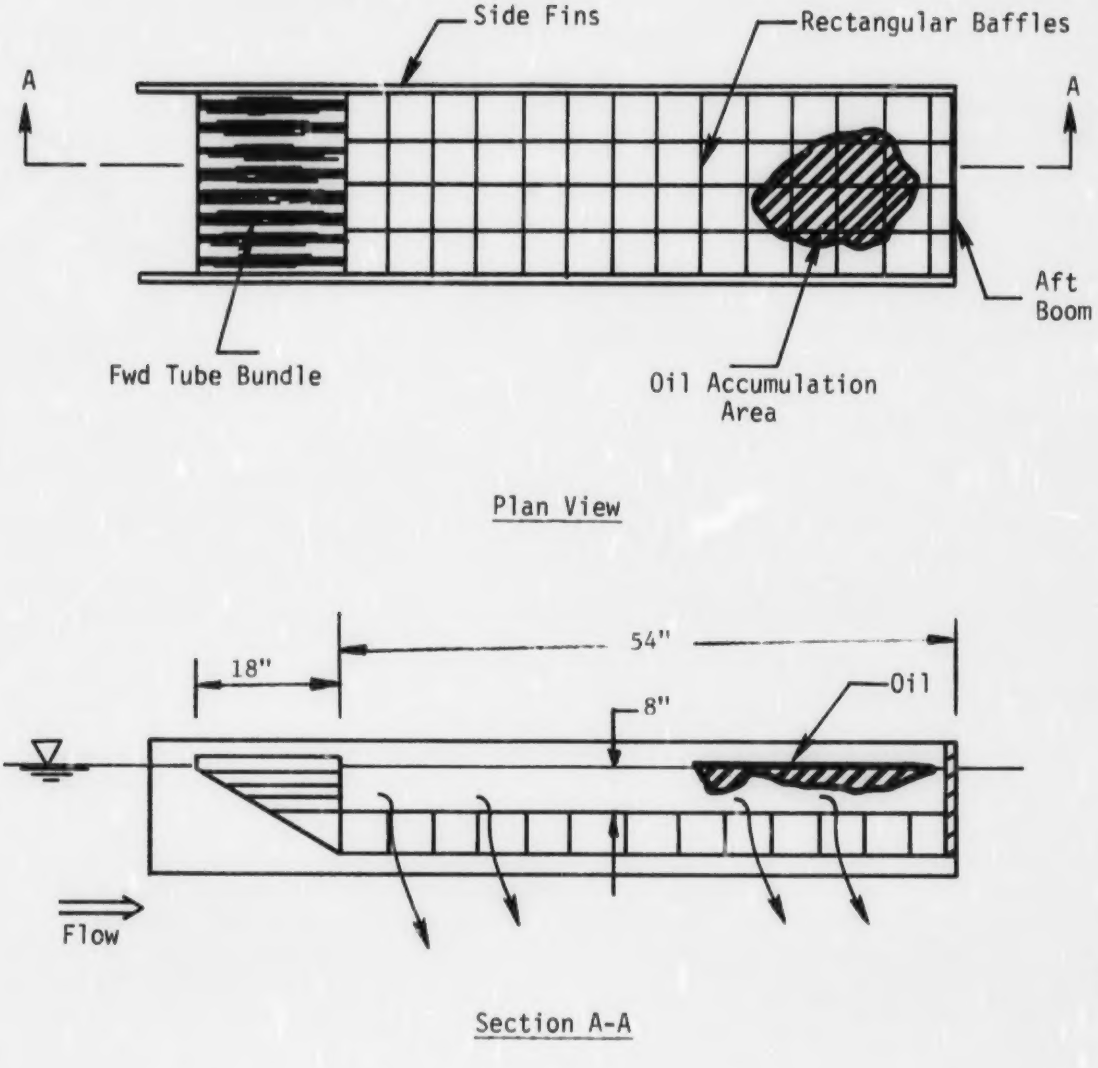

Side Fins
Rectangular Baffles
A
A
Aft Boom
Fwd Tube Bundle
Oil Accumulation Area
Plan View
18"
54"
Oil
8"
Flow
Section A-A

FIGURE 19 - REVISED BAFFLE CONCEPT

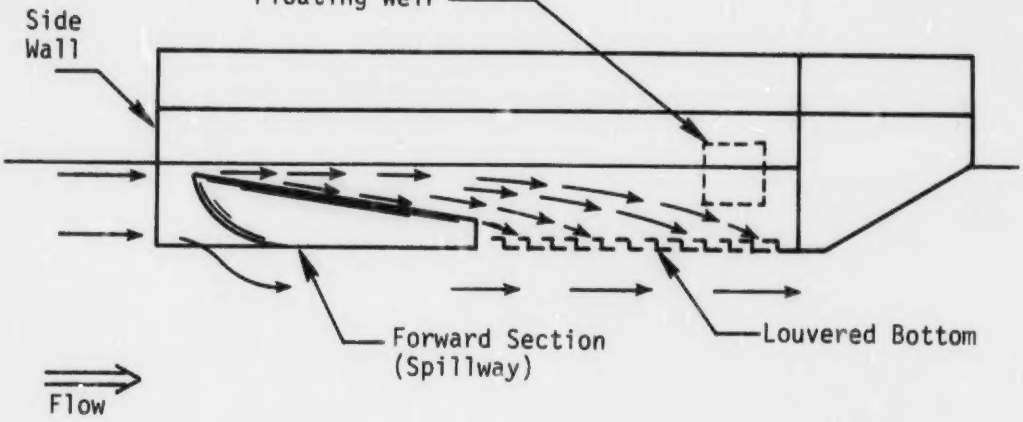

Floating Weir
Side Wall
Forward Section (Spillway)
Louvered Bottom
Flow

FIGURE 20 - A PRELIMINARY CONFIGURATION FOR PROJECT SEA DRAGON MODEL TESTED BY THE GARRETT CORPORATION

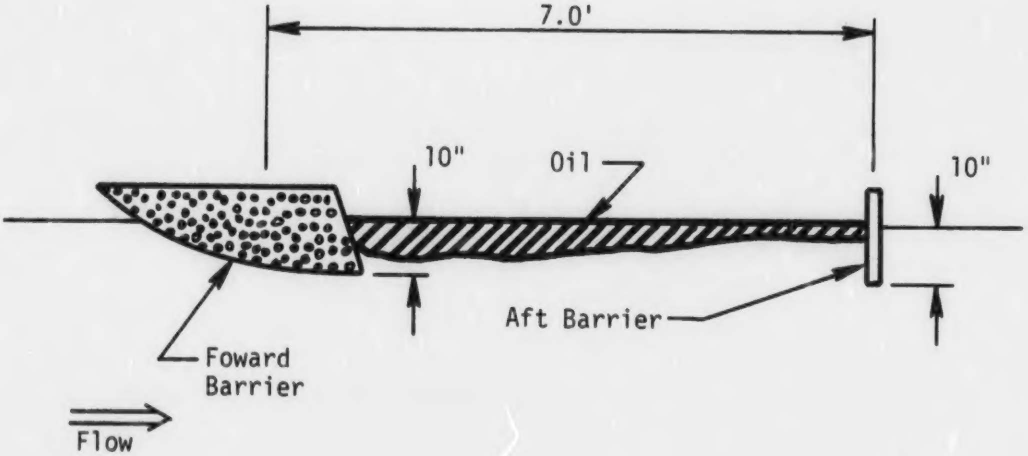

7.0'
10"
Oil
10"
Aft Barrier
Foward Barrier
Flow

FIGURE 21 - DOUBLE-BOOM CONCEPT TESTED BY ATLANTIC RESEARCH CORPORATION

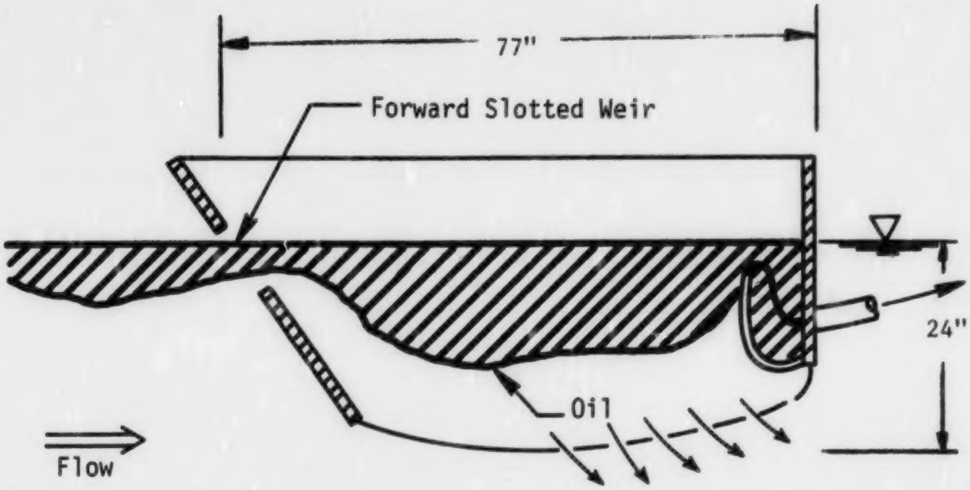

77"
Forward Slotted Weir
24"
Oil
Flow

FIGURE 22 - OCEAN SYSTEMS DYNAMIC KEEL CONCEPT

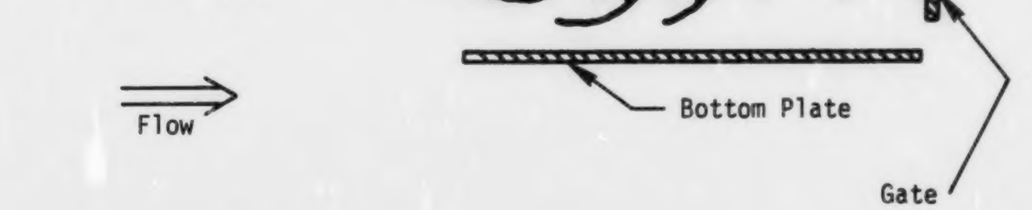

Inclined Plane
Oil
Bottom Plate
Flow
Gate

FIGURE 23 - JBF FIXED, INCLINED-PLANE CONCEPT

velocity produces smaller densimetric Froude numbers than that for a conventional boom. Their means of scaling these results to larger versions is unclear.

The JBF Scientific Corporation (8) developed the SHOC, an inverted, inclined-plane skimmer (See Figure 23), for the EPA. Their concept, although reasonably effective when used as a skimmer at moderate currents, would pose problems when used as an unconventional boom at high velocities.

During the test program reported here, the Pace Company (Toronto, Canada) developed and placed on the market a flexible double boom configuration for use in fast-moving waters. The boom profile is sketched in Figure 24. Oil and water enter the forward net section below the forward float; then oil is accumulated and (some) water passes through the water-permeable aft skirt section. Sufficient test data are not presently available on this boom.

Finally, a number of different high current control concepts (9,10), some applicable to both booms and skimmers, are presently in various stages of development. This research, directed toward controlling oil in 4 to 10-knot currents, is sponsored by the U.S. Coast Guard and the U.S. Environmental Protection Agency.

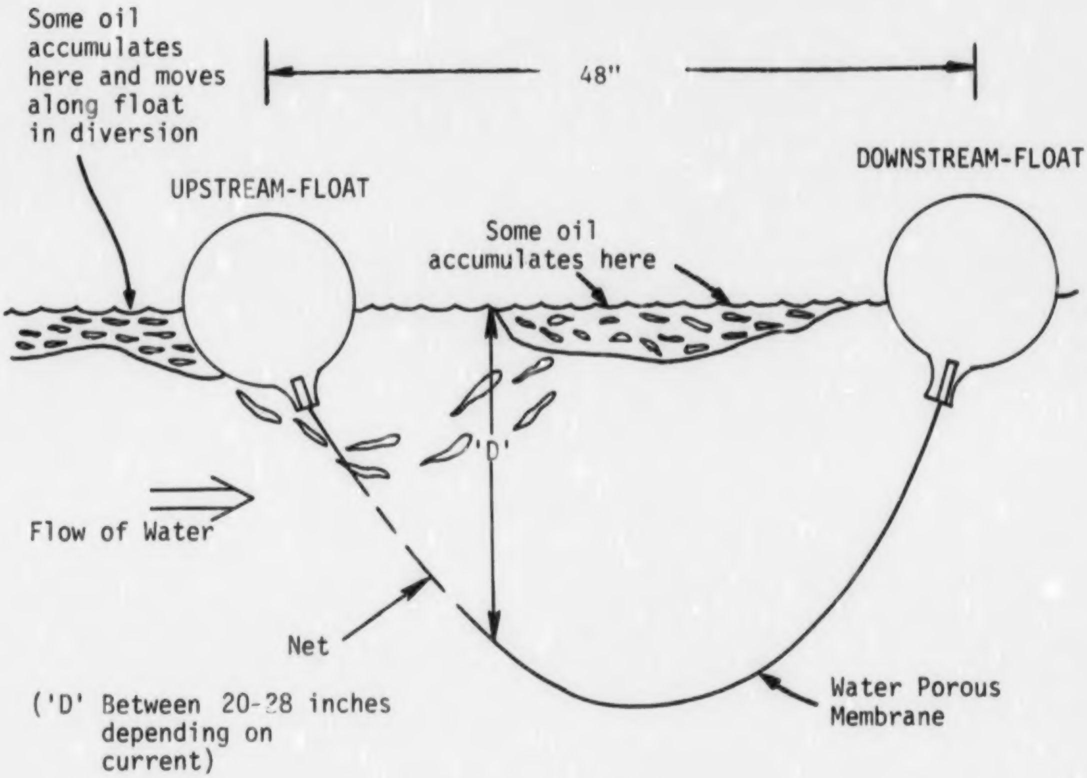

Some oil
accumulates
here and moves
along float
in diversion
48"
DOWNSTREAM-FLOAT
UPSTREAM-FLOAT
Some oil
accumulates here
'D'
Flow of Water
Net
('D' Between 20-28 inches
depending on
current)
Water Porous
Membrane

FIGURE 24 - PACE FLEXIBLE DOUBLE BOOM CONCEPT

VI. INITIAL BAFFLE STUDIES

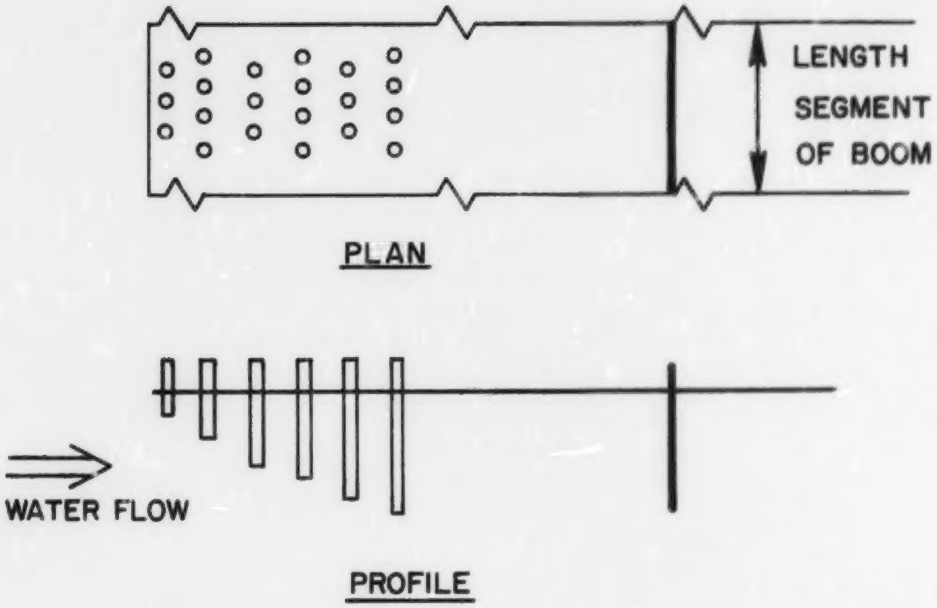
INTRODUCTION

The objective of the initial baffle studies which Shell conducted under this contract with the EPA was to determine what types of baffles might be useful for diffusing flow when incorporated in a high-current boom design. The approach used was to examine and improve two-dimensional models of candidate baffles by iterative tests in a closed-loop current tank using PVC beads to simulate oil. The most successful candidate was subjected to further 2-D model tests and then tested and modified in a wave/tow tank using oil. A series of 10 full-scale boom modules were built and tested further under three-dimensional conditions and finally demonstrated at OHMSETT.

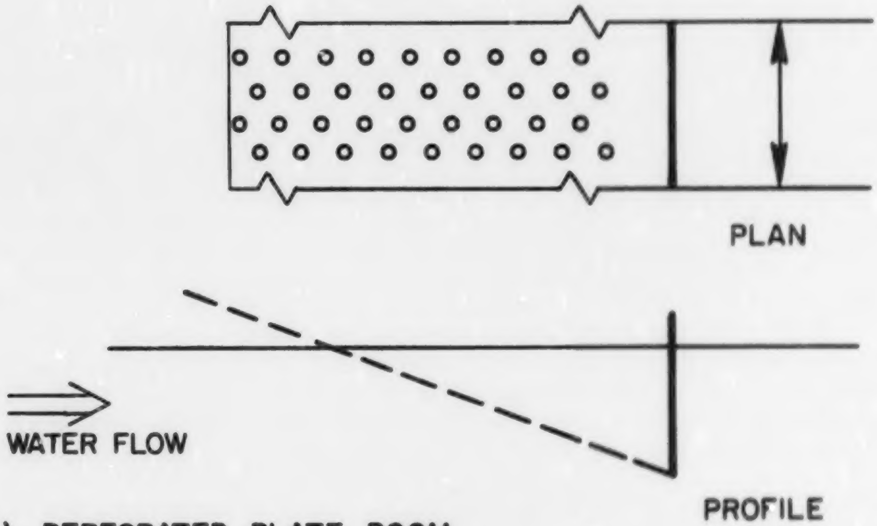
One clear constraint is that a flow diffusing baffle must perform effectively at various diversionary boom angles as well as normal to the flow. Also baffle candidates should have a relatively shallow draft in order to improve on conventional containment boom capabilities in fast-moving waters. Other considerations include lack of debris-fouling problems, wave conformance, and simplicity of design (hence economy).

Two different baffle configurations were chosen for initial experimentation. They are the inclined, perforated-plate, and the stub-tube array baffles shown in Figure 25. Previous Shell investigations indicate that baffle candidates should have relatively large openings, (as contrasted with small ones like small mesh nets and screens). Screens cause prolific small-diameter droplets to form as oil passes through. Droplets sweep under the barrier before they can recoalesce, causing substantial oil losses. Both of the candidates have large open-area-to-total-area percentages as indicated in the figure. Also, both candidates accommodate moderate changes in diversionary flow angle without significantly changing the flow-baffling capability. One form of stub-tube array baffle is used in the (API) Open Seas Skimmer design (1), but that baffle is designed specifically for offshore waves and is not necessarily optimal for high currents. In this program we have attempted to optimize the stub-tube baffle primarily for high currents (but in the presence of river-type waves). The perforated plate baffle, on the other hand, is likely simpler to construct than the stub-tube one and it should accommodate debris better.

Our experimental approach was to first study the behavior of a given baffle in water flow alone. By not using oil, underwater observations were not clouded and tests could be conducted more quickly and economically. The Shell Current Tank, shown in Figure 26, was used for this series of experiments. During tests a reference velocity (upstream from the test section) was continuously recorded using a Marine Advisor's 5-inch (See English-Metric Conversion Table, Appendix G) Ducted Current Meter. Local velocity readings upstream and downstream of the baffle array were made using a small A. Ott Kempten Model C-1


LENGTH
SEGMENT
OF BOOM
PLAN
WATER FLOW
PROFILE

(a) STUB TUBE ARRAY BOOM


PLAN
WATER FLOW
PROFILE

(b) PERFORATED PLATE BOOM

FIGURE 25 - INITIAL BAFFLE CANDIDATES FOR THE SHELL STUDY

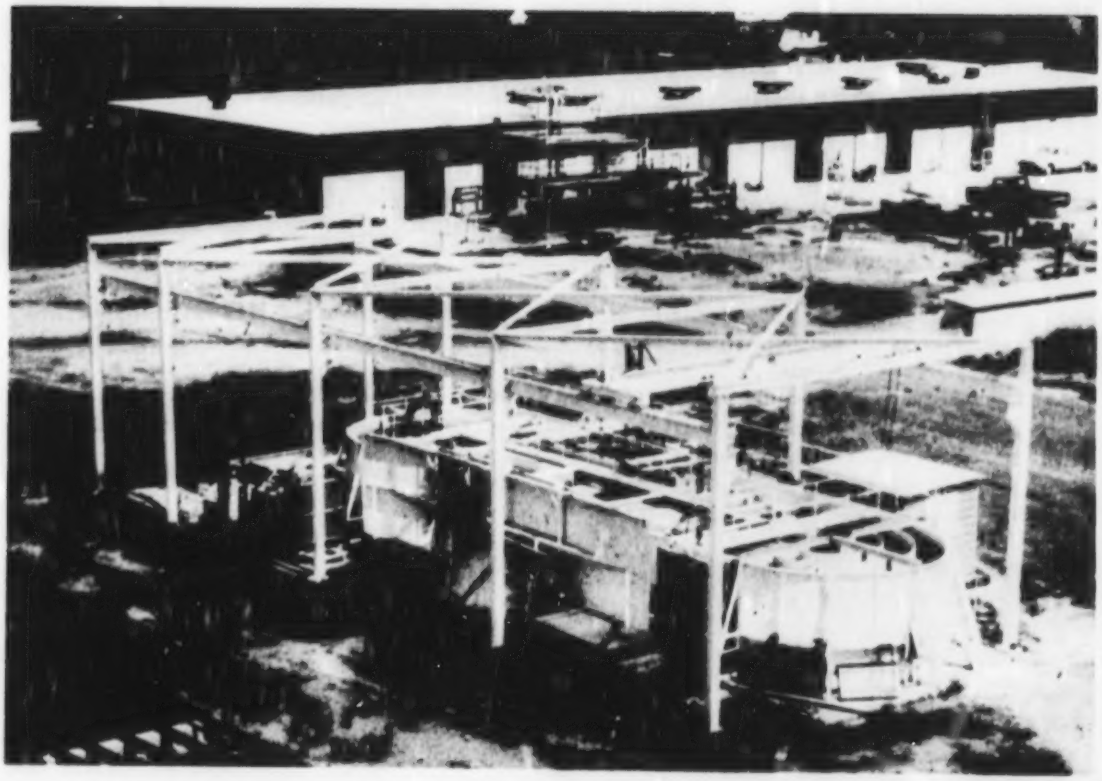


FIGURE 26 - SHELL CURRENT TANK
(GASMER LOCATION)

non-ducted propeller-type meter. Revolutions of the propeller per thirty second interval were electromagnetically counted and the counts were converted by a linear equation to the velocity in feet per second. Flow directions were determined using streamers. A qualitative measure of the oil containment capacity of a baffle-boom profile was obtained by placing sawdust or 0.9 specific gravity PVC beads in the water in front of the device and determining the approximate quantity accumulated by the device. Of course, the beads do not simulate the surface properties and viscosity of spilled oils, but they are rapid and efficient for qualitative testing and do afford a rough measure of the comparative effect of oil specific gravity on the oil retention capacity of a baffle-boom combination. Numerous photographs were taken to document the observations made during the experimental program.

SUMMARY

The perforated plate boom profile shown in Figure 27 has been found to be better than the stub-tube boom in Figure 28. The choice was based primarily on the capacity of the two-dimensional boom profiles to retain simulated oil (0.9 sp. gr. PVC beads). The full scale inclined perforated-plate profile collected between 90 and 100% of the beads encountered at 2.4 knots. The stub-tube profile tested at a geometric scale of 78% of full scale, retained 90 to 100% of the beads at a velocity of 1.75 knots. Using an optimistic scaling law based on the (single fluid) Froude number, the model tests on the stub-tube profile predict 90 to 100% simulated oil retention at a prototype velocity of 1.97 knots. Thus the inclined plate profile shows the same retention capacity at a free-stream velocity 23% greater than for the stub-tube profile.

Secondary considerations involved in selecting the inclined plate profile (Figure 27) were the:

1. estimated effect of debris on the profile,
2. ability to design a buoyant upstream structure in which flotation does not reduce the effectiveness of the boom,
3. fabrication complexity of the profile, and
4. projected structural adequacy and dynamic stability of the final boom arrangement.

The design of Figure 27 was later altered based on further tow testing with oil.

STUB-TUBE BAFFLE EXPERIMENTS (Model Scale)

Various arrays of stub tubes were placed in the test section of the current tank to explore their capacity to cause a velocity drop while minimizing turbulence and allowing simulated contaminents (initially sawdust and later PVC beads) to pass through on the water's surface. Figure 29 shows the general test set-up used in these experiments. Details of experimental interactions are contained in Appendix A.

To explore the effects of scale on the performance of these stub-tube arrays, several sizes of tubes and spacings were investigated. We assumed that flow effects would basically scale using the Froude number. This number is normally utilized in cases of surface-piercing solid objects in a fluid flow field. Consequently, in Froude scaling, lengths scale geometrically and velocities scale as the square root of the geometric scale. "Full scale" was arbitrarily selected as a tube diameter of 1.68 inches.

In the first twelve experimental conditions, called SM (for stub-tube model) -1 through SM-12, we investigated various tube diameters, orientations, and array spacings. With arrays having uniform longitudial and transverse spacings, the pressure drop caused by the baffle was concentrated near the first three rows. Turbulence was generally intense there and quite calm in subsequent downstream rows. We increased the spacing of the first two rows to reduce the local turbulence, but this was to no avail. Perhaps one could experiment further with altering spacings to a more optimum condition, but we observed that even a single tube upstream of an array magnified the turbulence at the front of that array. Then we decided to try means to reduce the ventilation phenomenum (air entrained in the water just behind a surface-piercing tube). Plastic streamers were slipped on an individual tube to make it look like a surface-piercing symmetrical "wing" shape in order to reduce vortex formations. This had a beneficial effect on ventilation. Also horizontal fins (like that used on the submerged leg of an outboard motor) were added. We observed that with a single tube, ventilation was reduced. The problem is that the vertical component of turbulence generated is unacceptably high, and neither the streamer nor the fin reduced it sufficiently to avoid oil loss.

While experimenting with a row of tubes using fins, we noticed that flow downdraft was less when the row was placed at an upstream or a downstream angle, rather than vertical. Accordingly, we explored both upstream and downstream angular changes to find a condition that produced less severe turbulence. In tests SM-8 through SM-11 we experimented with a "V" shape (in profile) with the first row of tubes slanting downstream and below and the second row slanting upstream and below such that the lower ends of the tubes in both rows formed the base of the "V". Having found a suitable stub-tube arrangement, we experimented with three different tube diameters, all geometrically similar.

Experiments SM-12 through SM-31 use the same baffle arrangement as was used in SM-8: By trial and error we chose barrier draft and distance downstream of the array, using retention of PVC beads as a basis for selection. The maximum model velocity for these tests was 3 fps which scales to 4.2 fps (2.5 knots) if 3.31-inch tubes were used as prototype size. In the last experiment, SM-31, a horizontal board was placed at mid-draft between the legs of the first two rows (forming the "V"). This improvement allowed a bead retention of 93 percent at 3 fps.

At this point the configuration of the stub-tube baffle boom was considered satisfactory, and the design was frozen. Following similar development of the perforated plate baffle concept, the two concepts were compared.

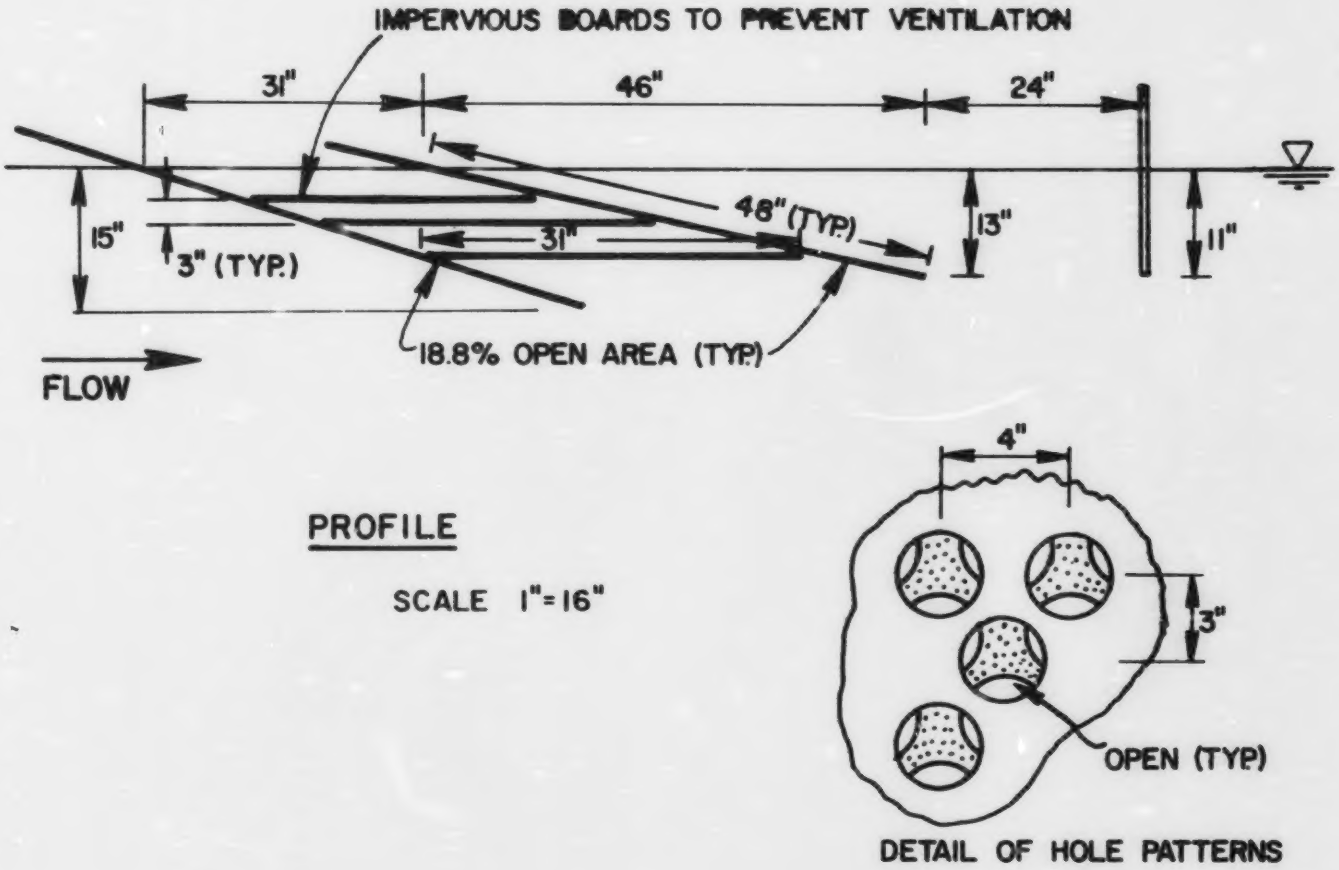

IMPERVIOUS BOARDS TO PREVENT VENTILATION
31"
46"
24"
48" (TYP.)
13"
11"
31"
15"
3" (TYP.)
18.8% OPEN AREA (TYP.)
FLOW
PROFILE
SCALE 1"=16"
4"
3"
OPEN (TYP.)
DETAIL OF HOLE PATTERNS

FIGURE 27 - OPTIMUM INCLINED PLATE BAFFLE BOOM ARRANGEMENT
BASED ON FULL SCALE TESTS IN CURRENT TANK

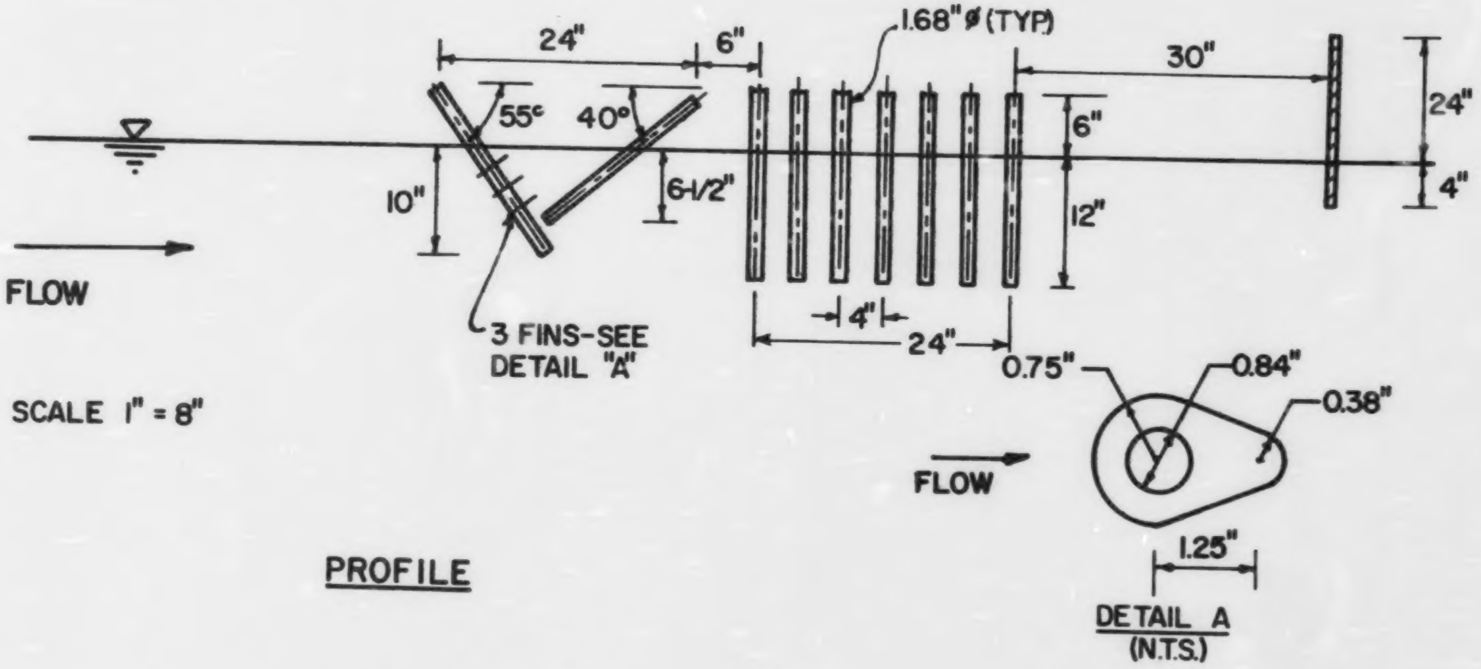

24"
6"
1.68" ø (TYP.)
30"
24"
4"
55°
40°
10"
6-1/2"
6"
12"
FLOW
3 FINS-SEE
DETAIL "A"
4"
24"
0.75"
0.84"
0.38"
SCALE 1" = 8"
FLOW
1.25"
PROFILE
DETAIL A
(N.T.S.)

FIGURE 28 - TENTATIVE OPTIMUM STUB TUBE BAFFLE BOOM ARRANGEMENT BASED ON ONE-HALF SCALE MODEL TESTS

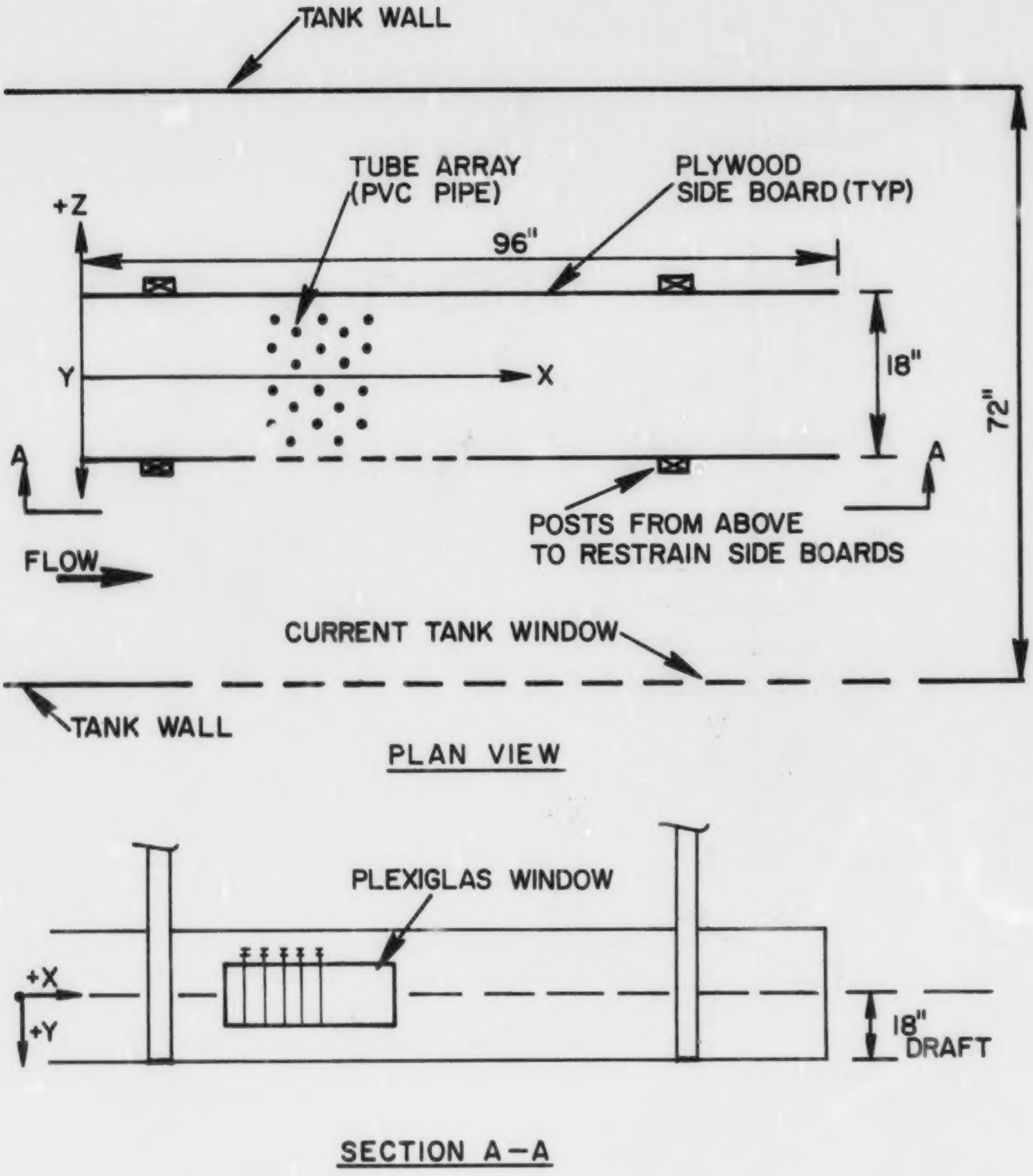

TANK WALL
TUBE ARRAY (PVC PIPE)
PLYWOOD SIDE BOARD (TYP)
+Z
96"
Y
X
18"
72"
A
A
POSTS FROM ABOVE TO RESTRAIN SIDE BOARDS
FLOW
CURRENT TANK WINDOW
TANK WALL
PLAN VIEW
PLEXIGLAS WINDOW
+X
+Y
18" DRAFT
SECTION A-A

FIGURE 29 - TEST SETUP OF STUB TUBE ARRAY IN CURRENT TANK (SIDE BOARDS PREVENT 3D EFFECTS)

PERFORATED-PLATE BAFFLE EXPERIMENTS

A second candidate design concept for the high-current boom is the inclined, perforated-plate baffle shown previously in Figure 27. The initial choice of baffle geometry for the current tank experiments was a 2-inch-diameter hole array on a flat plate such that a 46 percent open-area-to-total-area ratio is obtained. Using two identical plates and sliding one with respect to the other, open area ratios between 18.8 and 46.0 percent were obtained. These dimensions are considered "full scale" and not "model" as was the case for the stub-tube baffles. Because of the uncertainty of scaling laws for the inclined plate, we decided to test a full scale device. As before, local current measurements were made to determine velocity reduction and PVC beads were used to find the bead retention. Details of the trial and error experimentation are included in Appendix B.

Tests IPM (meaning "inclined plate model") -1 through IPM-13 were conducted using a single perforated plate, sloping below and downstream to achieve a planing configuration. The open-area ratio, plate inclination and downstream barrier draft and location were varied systematically. None of the changes produced an acceptable bead retention at a reference velocity of 3.75 fps, so an additional perforated plate was added to the design.

Then various combinations of plate orientations were tried, including both upstream and downstream slope angles of both plates. An anti-ventilation board was placed against the upstream plate at the waterline in some of the runs. The board had a positive effect in reducing ventilation, but it unfortunately increased bead losses. A Coke-case baffle (Coke case with the bottom out) was added to the design in an attempt to reduce turbulence (and bead losses) but this did not work. Finally, a configuration with two planing parallel plates was found to be promising. But even then fluid downflow between the two plates caused beads to pull under. The downflow problem was solved by placing three equidistant (solid) horizontal plates between the parallel perforated plates. This configuration, regarded as the best of the 33 tests, is shown in Figure 27. With both plates 18.8 percent open and with an 11-inch barrier downstream, approximately 80 percent of the beads were retained at 4.8 fps (2.9 knots, Experiment IPM-28). This compares with 93 percent bead retention at a (full scale equivalent) velocity of 4.2 fps (2.5 knots) for the sub-tube baffle (Experiment SM-31).

Since the perforated plate baffle worked well at a velocity of 0.6 fps (0.4 knot) higher than the sub-tube baffle, tow tank testing was conducted only with the perforated-plate baffle.

PRELIMINARY TOW TESTS - PERFORATED-PLATE BOOM CONCEPT

After the perforated-plate boom concept was chosen over the stub-tube boom, the experimental work changed from current tank tests without oil to wave/tow tank tests with oil. In the initial tow tests the perforated-plate boom model used in the current tank was fitted with outrigger flotation for towing. Figure 30 is a photograph of the boom profile, complete with outrigger flotation. The outriggers, of course, are only test fixtures.

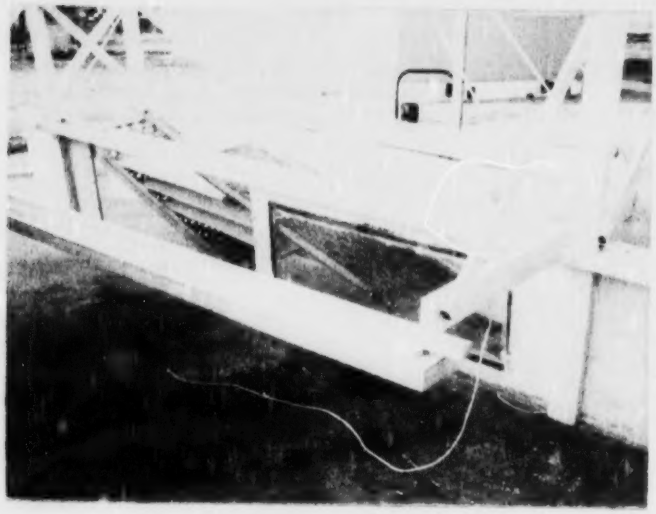
The initial objective of conducting tow tests on the previously current-tank-tested model was to find out if the design works as well with test oils as it did with the oil-simulating PVC beads. A few preliminary tow tests were run to examine this. We found in a qualitative way that the profile did not work as well with oil as it did with the beads. Because of this difference in behavior, we felt that further trial-and-error configuration improvement tests were warranted.

The first nine tow runs in this period used the configuration shown in Figure 25. The general test procedures are itemized in Appendix C of this report. The test oil is a light distillate resembling Number 2 Fuel Oil. Two types of tests were run: (a) a "constant flow rate" test in which oil is sprayed on the water in front of the device during a tow run, and (b) a "constant volume" test in which oil was placed inside the boom initially and then the boom is towed without applying additional oil.

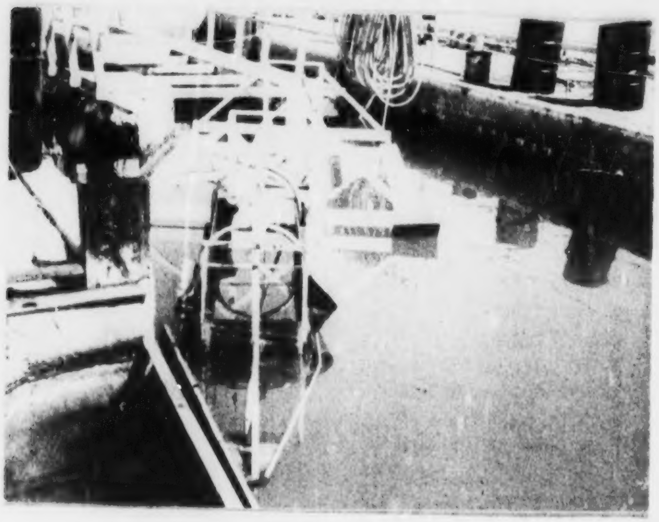
Summarized test results are shown in Table 1. We found that in the constant volume tests the percentage of oil retained in the sump area of the boom was about 90 percent. For the constant flow rate test, however, an average oil retention of about 65 percent was found. This means that a greater percentage of oil is lost under the device when the oil on the water's surface passes through the perforated plate toward the sump area. Apparently the oil lost drains down the front face of the perforated plate rather than passing through it.

A better boom, we think, is one that has the same percentage oil loss in both types of tests. Tests 10 and subsequent were conducted to find such a configuration. After trying various open-area ratios once again (this time with oil), various configurations of parallel but spaced-apart horizontal plate stacks, located between and behind the perforated plates, were tested. The plates were used to reduce flow downdraft and force oil horizontally through the perforated plate baffles.

Finally, in Tests 34 and 35 the most satisfactory configuration emerged. As shown in Figure 31. Configuration G, the design includes no second plate. Instead, a lower horizontal (and perforated) plate is added just upstream of the barrier, connecting the lower part of the forward perforated plate to that of the barrier. This submerged, perforated plate limits the water flow from the boom; consequently, a more open 46 percent plate could be used. Approximately 85 percent of the oil applied was retained by this boom at a tow velocity of 2.5 knots. Figure 32 is a sketch of the preferred perforated-plate boom configuration before flotation was added.



(A) Outrigger flotation attached to the Inclined plate boom for tow tests.



(B) Photograph showing the test fixture attached to the front of the boom.

FIGURE 30 - PHOTOGRAPHS OF TOW 2-D TEST MODEL (FULL SCALE) (SEE ALSO FIGURE C-1, APPENDIX C)

PERFORATED PLATE TOW TESTS

TABLE 1

Run No.	Boom Angle (deg)	% Open Plate 1	 Plate 2 or Bottom Plate	Tow Velocity (knots)	Oil Applied (gal)	Oil Retained or Diverted (gal)	% Oil Retained/ Diverted	Test Configurations (see Figure 31)
1	90	18.8	18.8	2.53	3.8	1.8	53[b]	A
2[a]	90	18.8	18.8	2.53	10.0	--	--[b,c]	
3[a]	90	18.8	18.8	2.53	20.0	2.0	89[b]	A
4	90	18.8	18.8	2.53	3.85	0.69	82[b,c]	A
5	90	18.8	18.8	2.53	3.75	0.6	84[d]	A
6[a]	90	18.8	18.8	2.53	18.0	1.98	89[d]	A
7[a]	90	18.8	18.8	3.07	18.0	0.48	97[e]	A
8	90	18.8	18.8	2.53	4.5	1.56	65[f]	A
9	90	24.5	18.8	2.53	4.5	2.38	47[f]	A
10[a]	90	24.5	18.8	2.53	10.0	--	--[f]	B
11[a]	90	46.0	31.0	2.53	10.0	--	--[c,g]	B
12	90	46.0	31.0	2.53	4.5	1.72	62[f]	B
13	90	46.0	46.0	2.53	4.5	1.45	68[f]	B
14[a]	90	46.0	46.0	2.53	10.0	0.56	94[c]	B
15[a]	90	46.0	46.0	2.53	9.44	0.75	92[c]	B
16[a]	90	36.0	46.0	2.53	4.5	1.94	50[f]	B
17	90	18.8	18.8	2.53	4.5	1.02	63[f]	B
18	90	18.8	18.8	2.53	4.5	--	--[h]	B
19	90	18.8	18.8	2.53	4.5	0.77	68[h]	C
20	90	18.8	18.8	2.53	3.82	2.69	70	D
21	90	35.0	18.8	2.53	3.65	2.63	72	D
22	90	35.0	18.8	2.53	--	--	--	E
23	90	18.8	18.8	2.53	4.14	3.28	79	E
24	90	18.8	36.0	2.53	4.03	2.74	68	E
25	90	18.8	18.8	2.53	3.74	2.77	74	E
26	90	18.8	18.8	2.53	3.98	3.12	78	E
27[i]	90	18.8	36.0	2.53	4.09	3.44	84	F
28[i]	90	18.8	18,8	2.53	4.57	3.95	86	F
29[i]	90	46.0	18.8	--	4.57	4.06	89	F
30[i]	90	46.0	18.8	2.53	4.20	3.76	87	F
31[i]	90	46.0	18.8	2.53	3.88	3.44	90	F
32[i]	90	46.0	24.5	2.53	4.29	3.66	85	F
33[i]	90	46.0	0	2.53	4.52	3.82	85	G[j]
34[i]	90	46.0	18.8	2.53	3.84	3.28	85	G[j]
35[i]	90	46.0	18.8	2.53	5.59	4.68	84	G[j]
36[i]	90	46.0	18.8	2.53	4.27	3.36	79	H
37[i]	90	46.0	18.8	2.53	4.49	3.52	78	H

TABLE 1 (Continued)

NOTES

a) Oil was applied inside the boom prior to towing. This is a "constant volume test". All other tests were constant flow rate tests.

b) We observed a small oil loss under the forward curtain during deceleration of boom.

c) We observed a slight oil sheen on the surface after the boom tow run. This was lost under the boom.

d) We detected only slight losses, less than c.

e) We observed no losses.

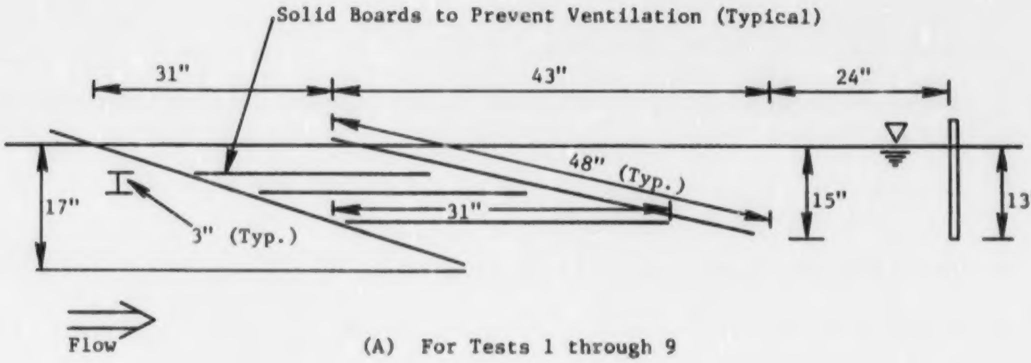
f) We observed oil droplets surfacing after the run, presumably lost under the boom. The loss was greater than Note 4, and quite noticeable.

g) This test was run to see if shorter flow control plates would be as effective as the longer ones used in previous runs. This is to simplify the design. The shortened plates are used subsequently.

h) A technician rode the skimmer to closely observe the oil loss mechanism. He saw numerous droplets below the surface inside the boom area. Some of these droplets passed under the boom, accounting for the loss.

i) Plate 2 was deleted, and a perforated bottom plate was added.

j) This configuration was judged to be the best considering all factors.


Solid Boards to Prevent Ventilation (Typical)
31"
43"
24"
48" (Typ.)
17"
3" (Typ.)
31"
15"
13"
Flow

(A) For Tests 1 through 9

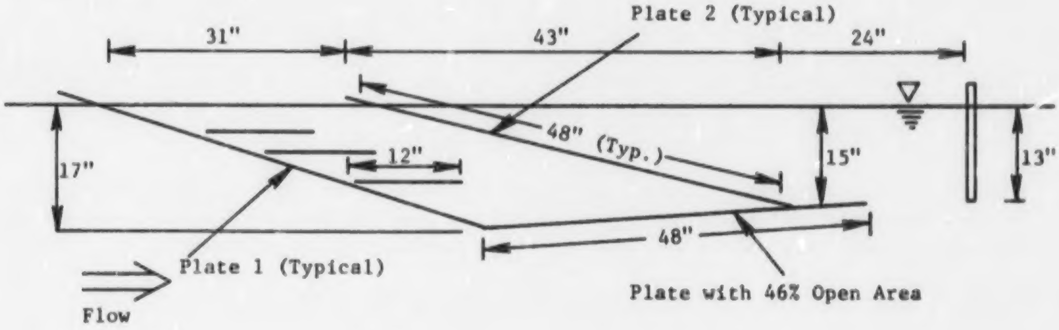
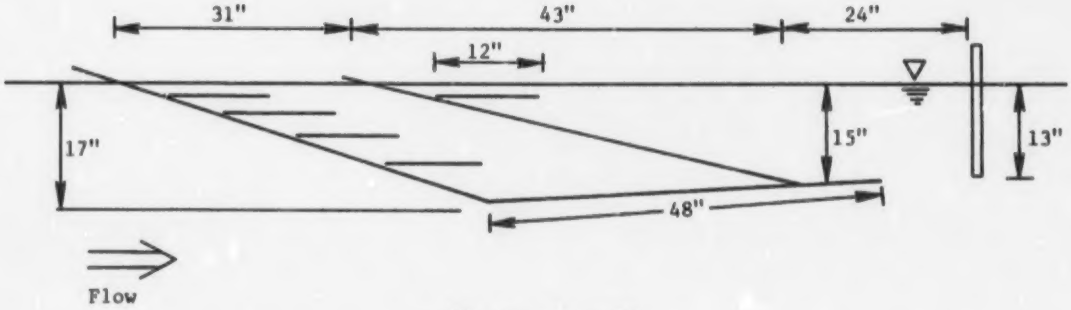


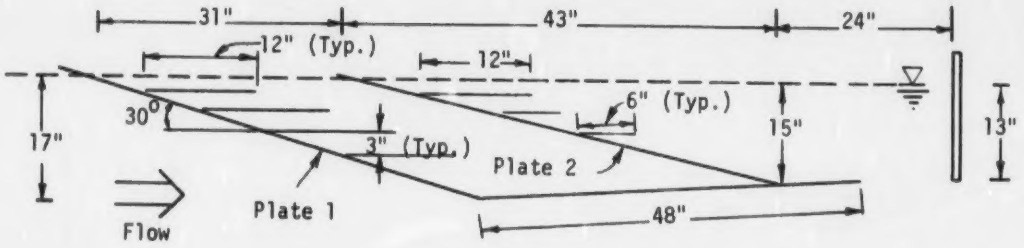
Plate 2 (Typical)
31"
43"
24"
48" (Typ.)
17"
12"
15"
13"
48"
Plate 1 (Typical)
Plate with 46% Open Area
Flow

(B) For Tests 10 through 18

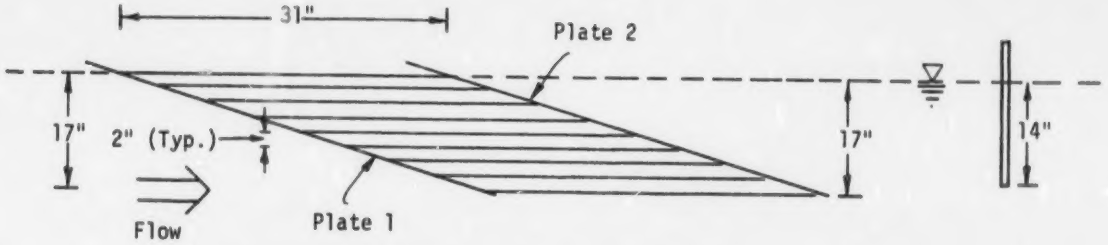

31"
43"
24"
12"
17"
15"
13"
48"
Flow

(C) For Test 19

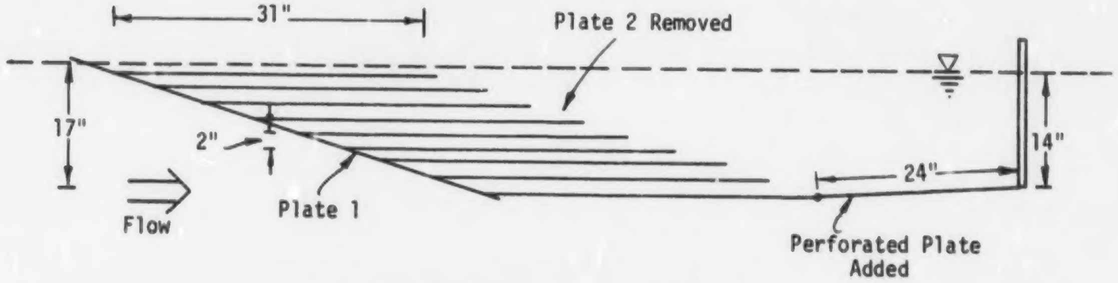
FIGURE 31 - TEST CONFIGURATIONS


31"
43"
24"
12" (Typ.)
12"
30°
17"
6" (Typ.)
15"
13"
3" (Typ.)
Plate 2
Plate 1
Flow
48"

Configuration (D) for Tests 20 and 21

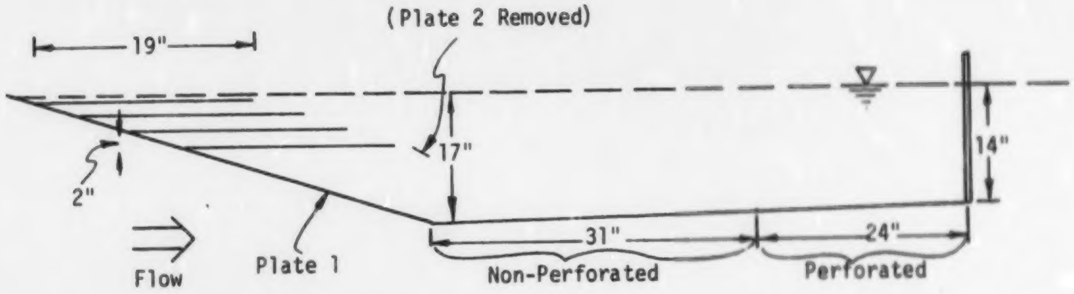

31"
Plate 2
17"
2" (Typ.)
17"
14"
Flow
Plate 1

Configuration (E) for Tests 22 through 26


31"
Plate 2 Removed
17"
2"
14"
24"
Flow
Plate 1
Perforated Plate Added

(F) for Tests 27 through 32

FIGURE 31 - (Continued)


(Plate 2 Removed)
19"
17"
14"
2"
Flow
Plate 1
31"
24"
Non-Perforated
Perforated

(G) For Tests 33 through 35

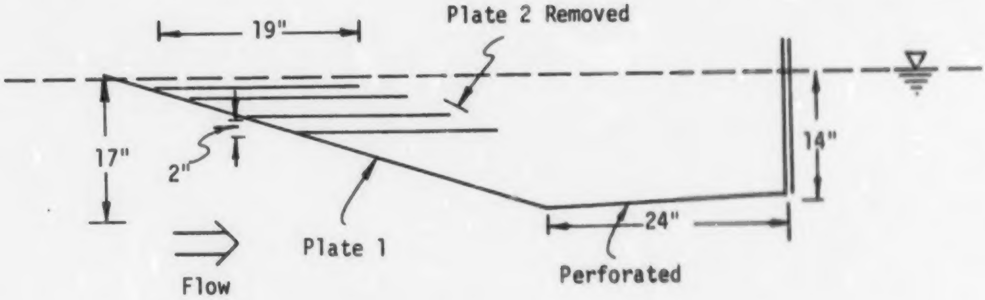


Plate 2 Removed
19"
17"
2"
14"
Flow
Plate 1
24"
Perforated

(H) For Tests 36 and 37 (shortened)

FIGURE 31 - (Continued)

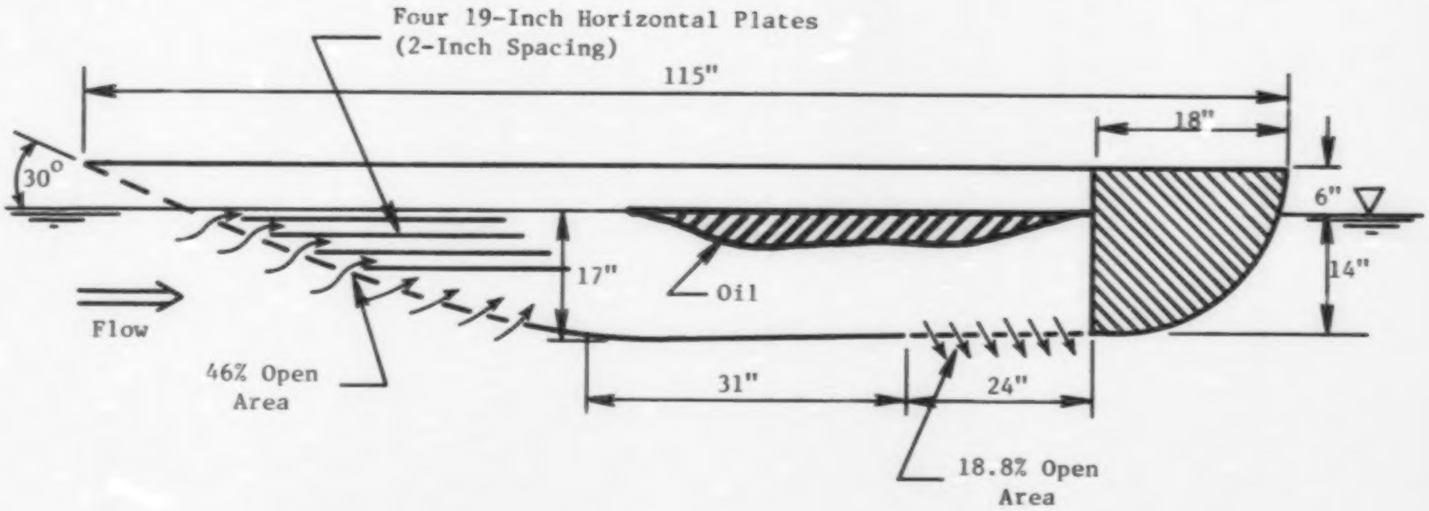

Four 19-Inch Horizontal Plates
(2-Inch Spacing)
115"
18"
30°
6"
14"
17"
Oil
Flow
46% Open
Area
31"
24"
18.8% Open
Area

FIGURE 32 - FINAL BOOM CONFIGURATION BEFORE FLOTATION IS ADDED (COMPARE WITH FIGURE 31G)

VII. CONFIRMING TESTS

TOW TESTS - HOUSTON

Following the preliminary two-dimensional (2-D) tow tests described in Section VI, a completely new, self-buoyant test device was fabricated. Figure 4 shows a photograph of the four-foot wide high-current module. Sidewalls (not shown) seal the sides of the boom for two-dimensional tow testing. We found it quite difficult to achieve suitable flotation in the leading upstream half of the boom. Only streamlined floatation could be used because flotation having a large projected frontal area would disturb the flow of oil (and water) into the boom.

The Shell wave tank has an unusual shape, shown in Figure 33. We were able to achieve a relatively long tow run (100 foot test section) with the four-foot-wide model, and the results of its tests are not affected by short test-time problems (as confirmed by OHMSETT tests). However, the tank's effective length was too short for a 20-foot wide device (Figure D-1), and the oil losses observed (See Appendix D) were generally less than those found later during tests at OHMSETT for all tow speeds above 2.0 knots (compare Tables 2 and 5).

In the 2-D tests at the Shell tank the four-foot-wide boom contained 85.2 percent of a 1.9 mm thick slick of No. 2 Fuel Oil at a 2.94 knot tow speed. In contrast, a conventional barrier of the same draft contained only 45.9 percent at a 2.25-knot tow speed (see Run Nos. 4 and 8, Table 2). Six-inch waves reduced the perforated-plate boom containment performance to 64.2 percent from a no-waves containment of 91.0 percent at approximately the same tow speed (2.28 and 2.35 knots respectively, Runs 1 and 8).

When Navy Special Fuel is used as the test oil, approximately 90 percent containment effectiveness is achieved at 1.5 knots as compared with approximately 2.25 knots for No. 2 Fuel Oil (interpolate Runs 15 and 17 and compare with Runs 1 and 2 respectively). We feel that density (not viscosity) is the primary reason for the observed difference in containment effectiveness (See Table 3).

Tests were performed by towing the boom at a constant velocity through a 100-foot long test segment, while applying oil on the water in front at a constant flow rate. Figure 34 shows the test arrangement. A remotely actuated drop-curtain was attached between the forward ends of the sidewalls. This curtain was dropped at the conclusion of the tow run to keep oil remaining in the boom at the end of a run separate from that lost under the boom during a run. Oil losses from the boom were collected and measured after each run. Detailed procedures were essentially the same as those used in the preliminary tow tests (See Appendix C).

Table 2 contains test conditions and results for 18 tow runs included in this test set. Table 3 shows the test oil properties. During the first four tests using No. 2 Fuel Oil, the percentage of oil lost during a run compared with that applied was less than 15 percent at speeds up to 3 knots, in the absence of waves. A 6-inch high, 2.8 second period wave increased the loss to almost 50 percent at 3 knots. Reducing the tow speed to 2.2 knots decreased the loss to 35 percent in the presence of the wave. If Test 10 is compared with Tests 1 and 2, we see that the percent loss from the constant volume run is almost half of that lost from the constant flow rate runs. Thus oil losses from inside the boom down through the bottom are about the same as those caused by oncoming oil draining down the upstream face of the boom and underneath.

Tests 12 through 17 were run using Navy Special fuel oil having a specific gravity of 0.968 at 80°F [No. 2 Fuel Oil has a specific gravity of 0.858 at this temperature]. Using densimetric Froude number scaling, (Equation (1)), one can reduce the three-knot effectiveness of the boom with No. 2 Fuel Oil by the ratio of the square root of oil-water density differences of the two oils to find an equivalent result for Navy Special oil. The calculated prediction is that 15 percent of Navy Special oil should be lost at a velocity of about 1.4 knots: Test 17 provides approximate proof of this scaling law. A comparison of Run 16 with Run 14 (both at 2.3 knots) shows that losses were evenly distributed between losses under the front face and losses through the submerged perforated bottom for Navy Special oil.

Tests 12 and 13 showed that with the denser Navy Special oil the deleterious effects of waves (in the 2-D tests particularly) were significant. Later tests at OHMSETT revealed that waves were not as much of a problem as encountered in these tests.

Finally, Test 18 was run to show that without the perforated baffle assembly in front of the downstream barrier, significant oil losses would occur. Comparing Tests 1 and 18, we see clearly that at about 2.3 knots the high current boom lost only 9 percent whereas the "baffle-less" boom of the same draft lost 54 percent of the oil applied.

THREE-DIMENSIONAL TOW TESTS - OHMSETT

The principal confirming tests were conducted at the U.S. EPA's Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) Facility at Leonardo, New Jersey. This 65-foot wide tank is 667 feet in length, so that relatively long test runs - in excess of 90 seconds at 3.5 knots - are possible. A more detailed summary of OHMSETT is included in Appendix E.

Primary emphasis of the OHMSETT tests of the high-current boom was on diversionary test runs, since the Shell tank was considered too short for reliable tests with wide oil control devices.

The objective of the tests was to obtain quantitative oil diversion efficiency data at tow speeds (and hence water currents) of 2.5 knots and above. A four-foot-long section of high current boom was assembled in a single rigid module for these tests. Figure 1 shows the boom under tow in the tank during a typical test run. A sketch of the boom mooring arrangement and overall tank dimensions is included as Figure 35. The boom profile is identical to that

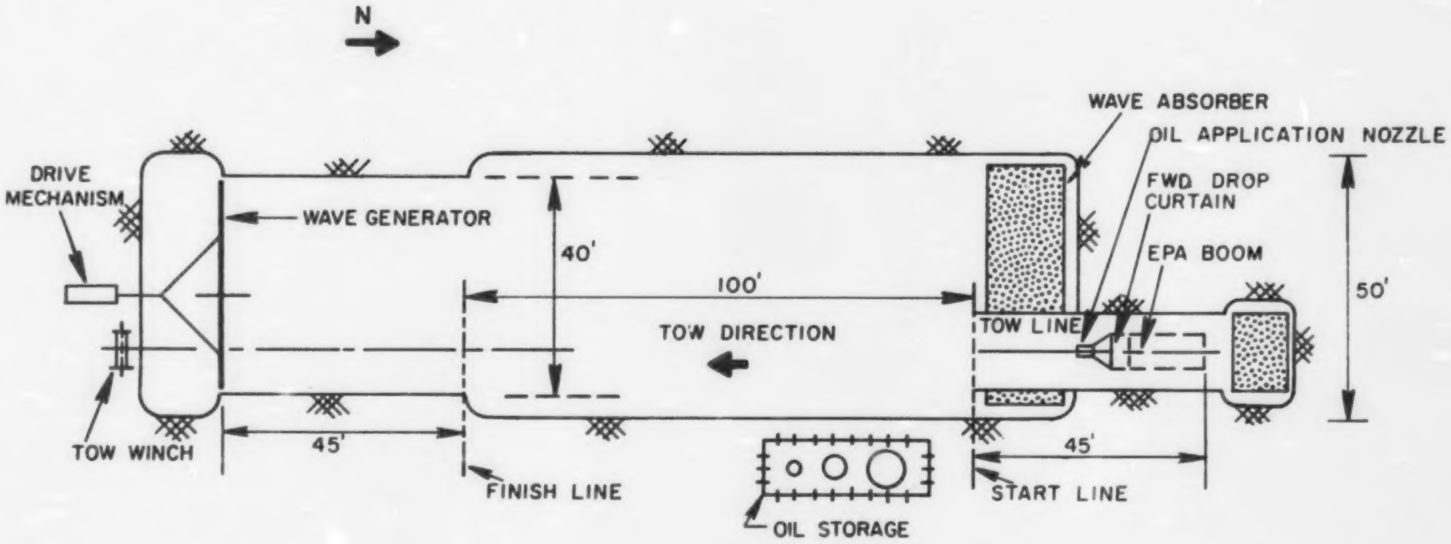

N
WAVE ABSORBER
OIL APPLICATION NOZZLE
DRIVE MECHANISM
WAVE GENERATOR
FWD DROP CURTAIN
EPA BOOM
40'
100'
50'
TOW DIRECTION
TOW LINE
TOW WINCH
45'
45'
FINISH LINE
START LINE
OIL STORAGE

FIGURE 33 - BOOM TEST SET-UP HOUSTON IN WAVE/TOW TANK

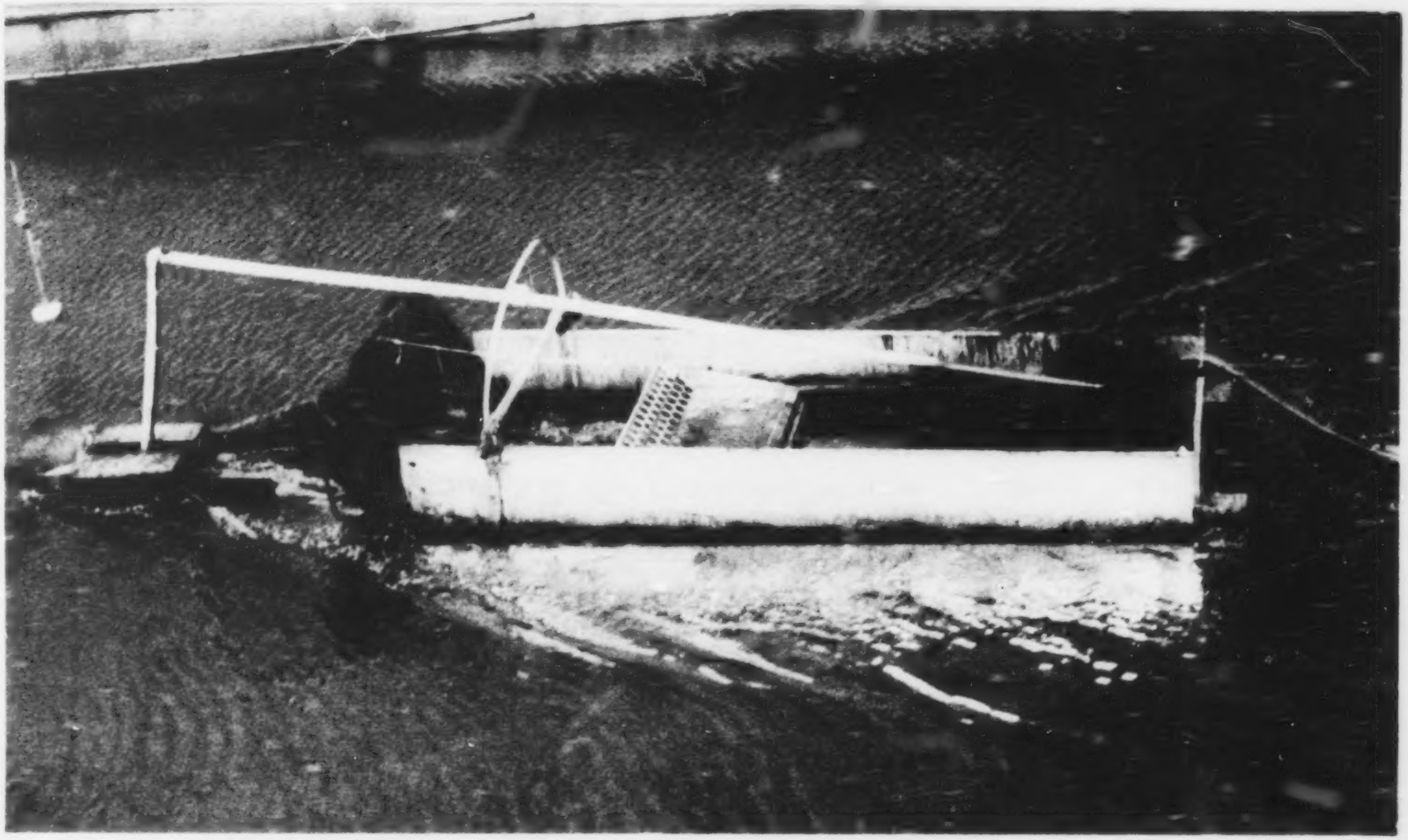


FIGURE 34 - BOOM SECTION DURING TOW TESTING. SIDE WALLS, FORWARD DROP CURTAIN AND OIL PIPING ARE ADDED FOR TEST PURPOSES

TWO-DIMENSIONAL BOOM TOW TESTS - FOUR-FOOT WIDE SECTION

TABLE 2

Run No.	Boom Angle (deg)	Test Oil	Tow Velocity, (knots)	Contact Time f) (sec)	Wave Height (in.)d)	Period (sec)	Oil Applied, (gal.)	Equivalent Thickness (mm)e)	Oil Retained/ Diverted (gals.)	%
1	90	No. 2 Fuel Oil	2.35		-	-	19.4	2.0	17.66	91.0
2	90	"	2.39		-	-	20.7	2.1	18.55	89.6
3	90	"	2.94		-	-	18.5	1.9	15.76	85.2
4	90	"	2.94		-	-	16.3	1.7	13.88	85.2
5	90	"	2.99		6"	-	17.2	1.8	8.93	51.9
6	90	"	1.31		-	-	22.0	2.2	21.78	99.0
7	90	"	2.19		6"	-	19.4	2.0	12.77	65.8
8	90	"	2.28		6"	-	17.0	1.7	10.91	64.2
9	90	"	1.72		6"	-	24.9	2.5	15.96	64.1a)
10b)	90	"	2.19		-	-	16.0	1.6	15.37	96.1
11	90	"	1.69		6"	-	2.17	2.2	17.19	79.2
12	90	Navy Special	1.75		6"	-	21.8	2.2	9.60	44.0
13	90	"	2.26		6"	-	19.7	2.0	5.80	29.4
14	90	"	2.28		-	-	21.1	2.2	8.10	38.4
15	90	"	1.79		-	-	20.7	2.1	16.55	80.0
16b)	90	"	2.29		-	-	16.6	1.7	13.67	82.3
17	90	"	1.37		-	-	26.9	2.7	24.77	92.1
18c)	90	Navy Distillateg)	2.28		-	-	21.1	2.1	9.68	45.9

a) Detectable loss around sides made this high.

b) "Preloaded" run using 16 gal. oil from previous run. This was run to show amount lost through bottom holes.

c) Baffles were removed; a straight vertical board was placed at the same 14" draft to see how much loss occurred when baffles are not used.

d) Wave steepness, H/L = 1/40.

e) Calculation based on a slick 4 feet wide.

f) Time boom under tow is in contact with test oil.

g) Navy distillate oil has the same properties as No. 2 Fuel Oil.

TABLE 3

MEASURED TEST OIL PROPERTIES
SHELL TESTS

Oil Type	Relationship of:			Surface Properties at 77°F		
	Temp. (°F)	Specific Gravity	Viscosity (cs)	Surface Tension (dyne/cm)	Interfacial Tension (dyne/cm)	Equilibrium Thickness ([redacted])
Navy Special Fuel Oil (MIL-F-859E)	100	0.9606	86	32.4	19.2 a)	4.90 b)
	75	0.9688	201			
	50	0.9722	593			
No. 2 Fuel Oil	100	0.8500	2.7	28.0	27.0 c)	
	80	0.8578	3.5			
	60	0.8653	4.5			

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a) tap water
b) NRL film and tap water
c) distilled water

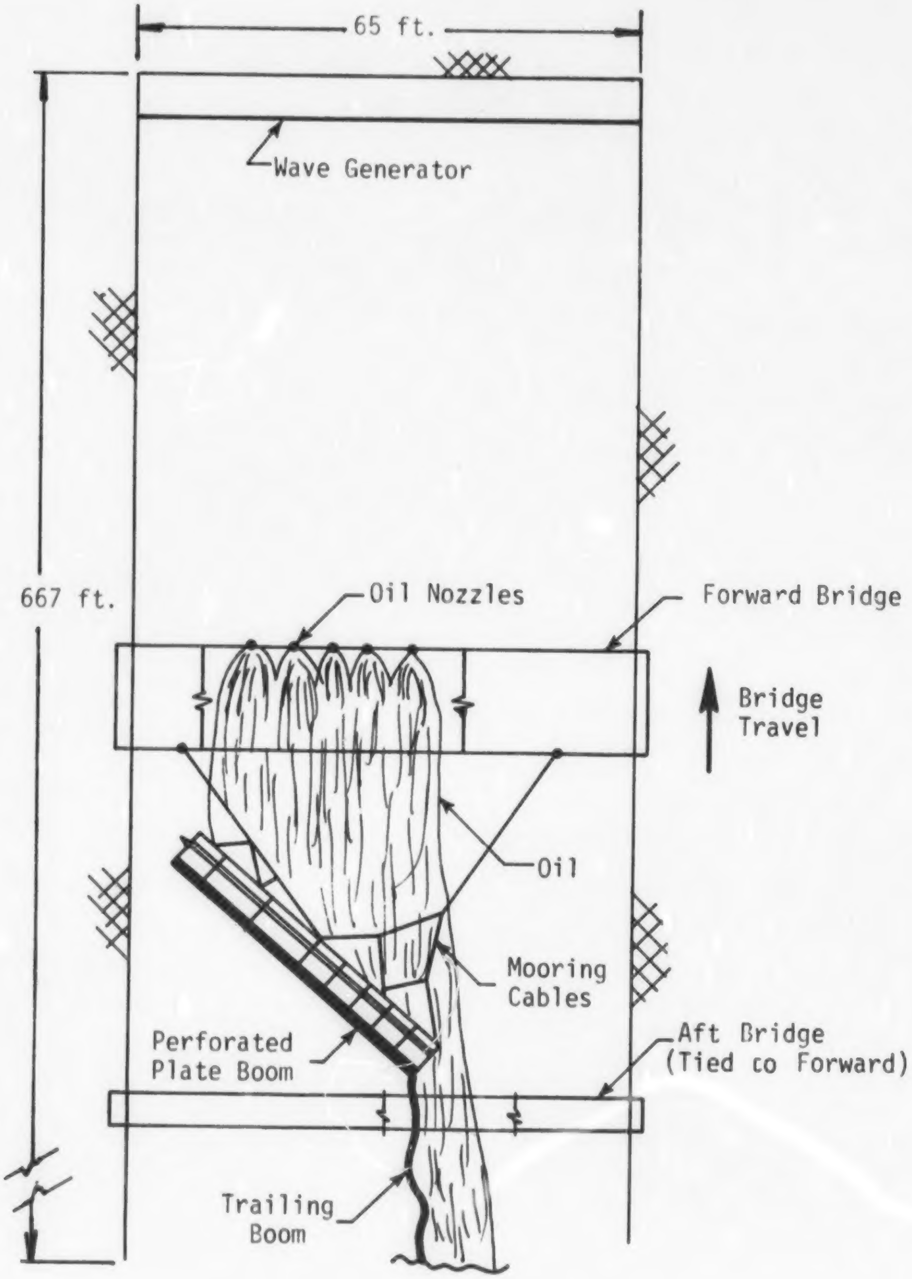
65 ft.
Wave Generator
667 ft.
Oil Nozzles
Forward Bridge
Bridge Travel
Oil
Mooring Cables
Perforated Plate Boom
Aft Bridge (Tied to Forward)
Trailing Boom

FIGURE 35 - SKETCH OF BOOM MOORING SYSTEM USED FOR OHMSETT TESTS

shown previously in Figure 4, since ten four-foot-wide segments were bolted together to form the 40 foot section.

Both containment (90° to the tow direction) and diversion tests (at 45°) were run at speeds from 2.2 to 3.5 knots. Test oils, described further in Table 4 were (a) slightly emulsified Sun 75 lube oil and (b) No. 2 Fuel Oil. The oils were applied at a constant flow rate (with multiple nozzles) on the water in front of the advancing boom. The approximate run time for each test was 90 seconds. Additional test information and photos are included as Appendix F.

Efficient diversion (30 percent or less oil loss under or over the boom) was achieved using the denser Sun 75 oil at a tow speed of 3.5 knots and a diversionary angle of 45°.

In the containment mode the pitch angle set by the rigging is critical for highest efficiency. Initial containment tests were completed before a rigging error was detected. This problem, we believe, accounted for the boom's flooding at tow speeds above 2.3 knots during these containment tests. Unfortunately, this problem was not determined in time to permit re-running the affected tests. Extrapolations to higher velocities can be made, however, using previously obtained 2-D test data. This rigging error has been corrected in the final boom design shown in Figure 6.

The OHMSETT test results formed the basis for the projected high-current boom performance summary shown previously in Figure 5. Extrapolations to oil types and diversionary angles not tested were made using the generally accepted densimetric Froude scaling law.

A summary of the test procedures used includes the following steps for a given tow test:

1. Start the wave generator (if waves are called for).
2. Accelerate the tow bridge and hence the high current boom to the desired tow speed.
3. Start despensing oil through the nozzles once the boom has reached a steady-state velocity.
4. Mark the start of the actual test run when oil first reaches the boom.
5. When the applied oil has contacted the boom for a 90 second period quickly stop the bridge, hence the boom and hence the oil losses (if any) under the boom.
6. Then quickly stop the oil application and the wave generator.
7. Manually collect and measure only that oil lost under or over the boom before it could be diverted. Diverted oil and oil remaining within the boom at the end of the run are not counted in the oil loss measurement.

8. Record sufficient data to determine (a) the oil application rate (b) the width of the slick approaching the boom and (c) the quantity of oil lost in addition to the usual records of tow speed and wave condition.

In this summary we assume that the boom has been rigged for towing and that the controlled variable settings have been made. Actual oil losses were concentrated for skimmer collection using the trailing separating boom (used to separate oil leaking under the boom from that successfully diverted by high-current boom) to encircle the lost oil.

A summary of the test results is shown in Table 5. Initially the 40-foot boom segment was placed at a 45° angle with the tow vector. Using Sun 75 oil, the first three tests explored the effects of increased velocity on the ability of the boom to divert oil. At 3.5 knots the diversion effectiveness reduced to 70 percent, meaning that 30 percent of the applied oil was lost under the high-current boom. Losses above 30 percent have been arbitrarily selected as being too high for efficient diversion. At 3 knots the losses were only 5 percent. Tests 4 and 5 indicate that 6-inch, 3 second period waves do not appreciably affect the diversion effectiveness of the boom. Eight-inch, 2 second waves applied in Test 6 were more choppy than the 6-inch, 3 second waves and a small reduction in performance is noted.

The boom was rerigged to allow towing at a 90° diversion angle (containment mode) and additional tests with Sun 75 oil were run. During an aborted test run (not included in the table) in which the oil application pump stopped midway into the run, the boom began to submerge. Poorly rigged cable moorings - the more likely candidate to cause the bow to dip and accumulate more water than can be relieved through the bottom perforations of the boom - were not suspected. Consequently the test program proceeded, and the two 90° tests (Tests 7 and 8) were run at reduced velocities to avoid boom submergence. At 2.3 knots, the limiting velocity to avoid submergence, 84 percent of the oil was successfully retained by the boom. Assuming that the normal component of velocity to the boom caused the oil loss, one can use the Test 3 results at 45° to predict a 70 percent oil retention at 2.5 knots at 90°. This prediction is further substantuated by referring to Table 2 which contains earlier 2-D test results conducted in Houston. In that table the oil loss results for the first four tests suggest that 90 percent retention capability should be expected at speeds above 2.3 knots. The percentages shown in Tables 2 and 5 differ slightly because the Houston test runs were shorter and less oil was lost during the runs. Also Table 2 shows that the same boom profile as used in these tests was successfully tested in Houston at 3 knots - but the test rigging there did not cause the boom to submerge.

Test 9 revealed that a 6-inch, 3 second wave did not alter the boom performance at about the same tow speed. An 8-inch, 2 second wave was not tested on the 90° boom because the boom's dimensions were such that it resonated.

The last two test runs were made using No. 2 Fuel oil as the test oil and arranging the boom to a 45° diversion angle. The diversion effectiveness in these tests was about the same as that obtained earlier with the Sun 75 oil. This result is not surprising because the specific gravities of the two oils are almost the same (Sun 75 oil is much more viscous than fuel oil, however).

TABLE 4

MEASURED TEST OIL PROPERTIES
OHMSETT TESTS

Oil Type	Relationship of:			Surface Properties at 88°F		
	Temp. (°F)	Specific Gravity	Viscosity (cs)	Surface Tension (dyne/cm)	Interfacial Tension (dyne/cm)	Equilibrium Thickness (mm)
Sunvis 75 (8 to 9% water)	80	0.9030	317	30.8	13.8a)	
	60	0.9111	578			
No. 2 Fuel Oil (5% water)	80	0.8470	7.1	28.8b)	13.6a,b)	
	60	0.8480	8.9			

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a) salt water
b) at 80°F

HIGH CURRENT BOOM TESTS AT OHMSETT
TABLE 5
RESULTS

Run No.	Boom Angle[a] (deg.)	Test Oil	Tow Velocity (knots)	Contact Time[b] (sec)	Wave Height (ins)	Wave Period (sec)	Oil Applied (gal)	Equivalent Thickness[c] (mm)	Oil Retained or Diverted (gal)	%
1	45	Sun 75	2.0	75	-	-	194	1.0	-	≈100[d]
2	45	"	3.0	54	-	-	208	0.8	-	90[d]
3	45	"	3.5	60	-	-	381	0.9	265	70
4	45	"	2.5	60	6	3	280	0.9	263	94
5	45	"	3.25	60	6	3	299	0.9	257	86
6	45	"	3.0	60	8	2	300	0.9	264	88
7[e]	90	"	2.3	60	-	-	371	1.6	214	85
8[e]	90	"	2.2	60	6	3	339	1.6	284	84
9	45	No. 2	3.0	60	-	-	404	1.5	-	87[d]
10	45	No. 2	3.0	60	8	2	427	1.4	-	85[d]

Footnotes:

[a] Angle is between boom and tank sidewall.
[b] Time boom under tow is in contact with test oil.
[c] Based on 30-foot slick width.
[d] Estimated.
[e] Rotating mooring cables caused boom to pitch downward, then the increased flow submerged the stern at speeds in excess of 2.3 knots. This can be easily corrected.

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APPENDIX A

DETAILS OF STUB-TUBE BAFFLE EXPERIMENTS

(SM-1 through SM-31)

A detailed step-by-step summary of the individual stub-tube model baffle experiments run in the Shell Current Tank (Figure 26) is found in Table A-1. Figures A-1 and A-2 show the configuration profiles, and Tables A-1 (for test SM-1 through SM-11) and A-2 show the principal dimensions. Figures A-3 through A-34 are selected photographs taken at various states of experimentation.

TABLE A-1

EXPERIMENTS WITH STUB TUBE ARRAY

Test No.	No. Tubes/ No. Rows	Size Tubes Inches	Z Spacing Inches	X Spacing Inches	Y Draft Inches	X Axis To 1st Row ℄ Inches	Vel.* Front/Back fps	Ref.[d] Vel. fps	Δ H Level Inches	See Figure	Remarks	Decision
SM-1	51/6	.84	2.0	2.0	6.0	31.0	1.17/21(1)	1.05	1.0	A-3- A-5	Look promising, did not pull sawdust under (top observation only).	Look at 2.0 fps.
SM-2	51/6	.84	2.0	2.0	6.0	31.0	2.26/.60(1)	2.1	1.0	A-6	Increased surface turbulence.	Increase X-spacings.
SM-3	51/6	.84	2.0	3,3,2,2,2	6.0	31.0	2.29/.66(1)	2.1	1.0		Installed glass side and saw bubbling action, ΔH and turbulence.	Increase spacing of tubes upstream.
SM-4	63/8	.84	4 (1st row) 2-3/8 (2nd row) 3 (all others)	4,4,3,3, 2,2,2	6.0	23.0	2.27/61(1)	2.15	1.0		Observed turbulence at 1st (3) rows and bubbling ventilation action.	Check original with 8 rows of tubes.
SM-5	68/8	.84	2.0	2.0	6.0	33.0	2.18/.57(1)	2.15	1.0		Reduced vortex action but still lost sawdust under.	Increase tube spacing.
SM-6	42/6	.84	2.5	5.0	6.0	30.0	2.32/.90(3)	2.15	.75		Downstream current did not decrease as needed, large amounts of turbulence were observed.	4 rows 2"℄, 4 rows 5"℄ (SM-7) Alter spacing to avoid localities of turbulence at front.
Sm-7	56/8	.84	2.5	2,2,4,5, 5,5,5	6.0	29.0	-/-	2.15	-	A-21	Vortices still predominate, hand held tubes between rows 1 & 2 and 2 & 3 reduced vortex action.	Decided to hand hold individual tubes using metal fins and streamers to reduce air ventilation bubbles and downdraft flow.

---

*Vel in front at X = 0, Vel in back at X - 48[1], X - 51[2], X = 56[3], X = 54[4]

Hand held a row of 0.84 inch tubes (2" transverse spacing) in front of seven rows of 0.84 inch tubes (2" spacing both axes):

(a) With 3 fins on each tube of the first row, the turbulence was minimized if the row of tubes was inclined 30° upstream from vertical.

(b) With the row pointing upstream as in (a) a second row of tubes with fins was placed in front using a 25° downstream angle. Turbulence was reduced but particles became entrapped between the second row of fins an- the first row of vertical tubes. These particles were caught in an upstream flow.

(c) The current was increased to 2.4 fps and turbulence increased. After the fins were removed from the second row (with the upstream angle) the turbulence decreased.

(d) This is measured velocity for the scale model. The equivalent velocity for full scale may be obtained by the formula.

TABLE A-1

EXPERIMENTS WITH STUB TUBE ARRAY (Continued)

Test No.	No. Tubes No. Rows	Size Tubes Inches	Z Spacing Inches	X Spacing Inches	Y Draft Inches	X Axis To 1st Row ℄ Inches	Vel.* Front/Back fps	Ref.$^{d)}$ Vel. fps	ΔH Level Inches	See Figure	Remarks	Decision
Single Tube Experiments:												
Hand held individual tubes to observe water flow:												
(a) .84" dia. tube with (1) fin - fin 1" max. under H_2O looked good, deeper created Vortices												
(b) .84" dia. tube without fin created vortices, upstream angle looked good												
(c) .84" dia. tube with streamer - looked good no vortices												See Figures A-7 through A-20
Hand held rows 2"℄ (8 tubes each) in front of 7 rows of 2: apart axis of alternating 9 and 8 tubes each 2"℄ Z-Axis.												
Tubes with 3 fins each, at 40° upstream with tubes all under H_2O looked good, no vortices.												
SM-8	76/9	.84	2.0	11,6.2,2, 2,2,2	6.0	18.0	2.19/.49$^{(2)}$	2.1	.75	A-22 A-23 A-24	First row (with fins) using a 25° downstream angle, second row 40° upstream angle (no fins). A 78° velocity reduction was achieved with only moderate turbulence.	This looks good, now try 1.08 inch tubes.
SM-9	60/8	1.076	2.37	2.5	7.5 & smaller	27.0	2.13/.44$^{(2)}$	1.95	1.0	A-25 A-26	Reducing the draft increases surface turbulence. Same velocity reduction as SM-8.	Decided to scale up using 1.31" OD tubes.
SM-10	48/8	1.314	3.0	3.125	9.35	24.0	2.05/.43$^{(4)}$	2.05	1.25	A-27	Some bubbling action, turbulence first 3 raws good, velocity reduction same.	See performance at 1.0 fps.
SM-11	48/8	1.314	3.0	3.125	9.35	24.0	1.11/.18$^{(4)}$	1.05	.75	A-27 A-28	Good velocity reduction no surface disturbance.	Process results, decide what arrays to use with a transverse barrier. Now add a rear barrier to achieve a baffle/barrier configuration.

TABLE A-1

TEST SUMMARY STUB TUBES

Test No.	No. Tubes/ No. Rows	Size Tubes Inches	Z Spacing Inches	X Spacing Inches	Y Draft Inches	X Axis To 1st Row ℄ Inches	Vel.* Front/Back fps	Ref. d) Vel. fps	Barrier Location X-Inches	Barrier Location Y-Draft	See Figure	Remarks	Decisions
SM-12	76/9	.84	2.0	11,4,2, 2,2,2,2	6.0	18.0	-/-	1.05	60	4	A-29 A-30	A 6" draft on barrier causes forward currents and turbulence, a 4" draft decreases action.	Place barrier further back.
SM-13	76/9	.84	2.0	"	6.0	18.0	-/-	1.05	72	4		A 4" draft causes forward currents; and a 2" draft decreases the currents.	Move barrier closer.
SM-14	76/9	.84	2.0	"	6.0	18.0	-/-	1.05	69	4		"	"
SM-15	76/9	.84	2.0	"	6.0	18.0	-/-	1.05	66	4		"	"
SM-16	76/9	.84	2.0	"	6.0	18.0	-/-	1.05	63	4		Upward turbulence was almost eliminated at boom.	Increase velocity.
SM-17	76/9	.84	2.0	"	6.0	18.0	-/-	2.0	60	1/2-8		1" draft of barrier was too shallow, 2"-8" - No vortices, but turbulence increased as depth increased.	Move barrier closer to tubes.
SM-18	76/9	.84	2.0	"	6.0	18.0	-/-	2.0	58	2-3		A barrier draft of 3" caused too much turbulence; at 2", turbulence was decreased.	Move barrier further away from tubes.
SM-19	76/9	.84	2.0	"	6.0	18.0	-/-	2.0	66	2"-6"		Boom draft of 2-8" caused upward currents at barrier on occasions with a 6" draft causing vortices to form.	Go to larger OD P.V.C. tubes.

TABLE A-1

TEST SUMMARY STUB TUBES (Continued)

Test No.	No. Tubes/ No. Rows	Size Tubes Inches	Z Spacing Inches	X Spacing Inches	Y Draft Inches	X Axis To 1st Row C_L Inches	Vel.* Front/Back fps	Ref.[d)] Vel. fps	Barrier Location X-Inches	Barrier Location Y-Draft	See Figure	Remarks	Decisions
SM-20	48/8	1.31	3.0	3.125	9.0	24.0	-/-	2.17	63	4-15		Draft of barrier had very little effect on surface of H_2O. Did not lose beads at this setting.	Increase distance between tubes and boom.
SM-21	48/8	1.31	3.0	3.125	9.0	24.0	-/-	2.17	75	4-10		With a boom draft of 10", vortices tried to form but would not pull beads under.	Move barrier further away from tubes.
SM-22	48/8	1.31	3.0	3.125	9.0	24.0	-/-	2.17	87	5-12		At a boom depth of 11-12", forward currents were created and should be maximum depth placement of boom.	Results not as good as SM-21. Try configuration of SM-21 at a higher velocity.
SM-23	48/8	1.31	3.0	3.125	9.0	24.0	-/-	4.0	75	6		Placing a rear barrier with a draft of 6" at X = 75" caused severe ventilation and turbulence.	Go back to the 0.84" tube array.
SM-24	76/9	0.84	2.0	1.0 (1st row)	6.0	20.0	-/-	3.9	64	3-8	A-31 A-32	Placing a 3 to 8" barrier at X = 64" caused interference waves between the tube array and the barrier.	Try even tube spacing.
SM-25	76/9	0.84	2.0	2.0	6.0	20.0	-/-	2.1	66	6		Plastic beads of 0.9 specific gravity were presented and 85% were retained by the boom.	Try higher velocity.
SM-26	76/9	0.84	2.0	2.0	6.0	20.0	-/-	2.6	66	6		Approximately 80% of the beads were retained by the boom.	Vary the barrier draft.

TABLE A-1

TEST SUMMARY STUB TUBES (Continued)

Test No.	No. Tubes/ No. Rows	Size Tubes Inches	Z Spacing Inches	X Spacing Inches	Y Draft Inches	X Axis To 1st Row ℄ Inches	Vel.* Front/Back fps	Ref.[d)] Vel. fps	Barrier Location		See Figure		
									X-Inches	Y-Draft			
SM-27				Same as SM-25				3.0	66	3-6		At 3.0 fps and 3" draft, 60% of the beads were retained for separate runs.	Return to the 1.31" tube array model.
SM-28	54/9	1.31	3.0	17 (1st row) 3.125 (all others)	8.25	18.0	-/-	2.5	77	8	A-33	With rear barrier at 20" and 8" draft, 90% of beads were retained.	Try higher velocity.
SM-29				Same as SM-28				2.9	77	8		An increase in velocity to 2.9 fps resulted in a retention percentage of 80.	Try deeper draft tubes and place barrier further downstream.
SM-30	64/9	1.31	3.0	17 (1st row) 3.125 (all others)	9.4	18.0	-/-	2.95	81	9		80% of the beads were retained.	
SM-31				Same as SM-30							A-34	A single board was placed horizontally between the first two inclined rows of tubes to eliminate downward turbulent flow. Bead retention was 93%.	

TABLE A-2

TESTS SM-1 THROUGH SM-11:

Use Figure A-1 configuration and Table A-1 Dimensions

TESTS SM-12 THROUGH SM-31:

Test No.	Vel. FPS	X_1 In.	X_2 In.	X_3 In.	X_4 In.	X_5 In.	X_6 In.	Y_4 In.	Y_5 In.
SM-12	1.05	18	29	33	45	60	--	6	4
SM-13	1.05	18	29	33	45	72	--	6	4
SM-14	1.05	18	29	33	45	69	--	6	4
SM-15	1.05	18	29	33	45	66	--	6	4
SM-16	1.05	18	29	33	45	63	--	6	4
SM-17	2.0	18	29	33	45	60	--	6	1/2"-8"
SM-18	2.0	18	29	33	45	58	--	6	2"-3"
SM-19	2.0	18	29	33	45	66	--	6	2"-6"
SM-20	2.17	a	a	24	46	63	--	9	4"-15"
SM-21	2.17	a	a	24	46	75	--	9	4"-10"
SM-22	2.17	a	a	24	46	87	--	9	5"-12"
SM-23	4.0	b	b	24	46	75	--	9	6
SM-24	3.9	20	32	35	47	64	--	6	3-8
SM-25	2.1	20	32	35	47	66	--	6	6
SM-26	2.6	20	32	35	47	66	--	6	6
SM-27	3.0	20	32	35	47	66	--	6	3-6
SM-28	2.5	18	35	38	57	77	--	8.25	8
SM-29	2.9	18	35	38	57	77	--	8.25	8
SM-30	2.95	18	35	38	57	81	--	9.4	9
SM-31[c]	2.95	18	35	38	57	81	--	9.4	9

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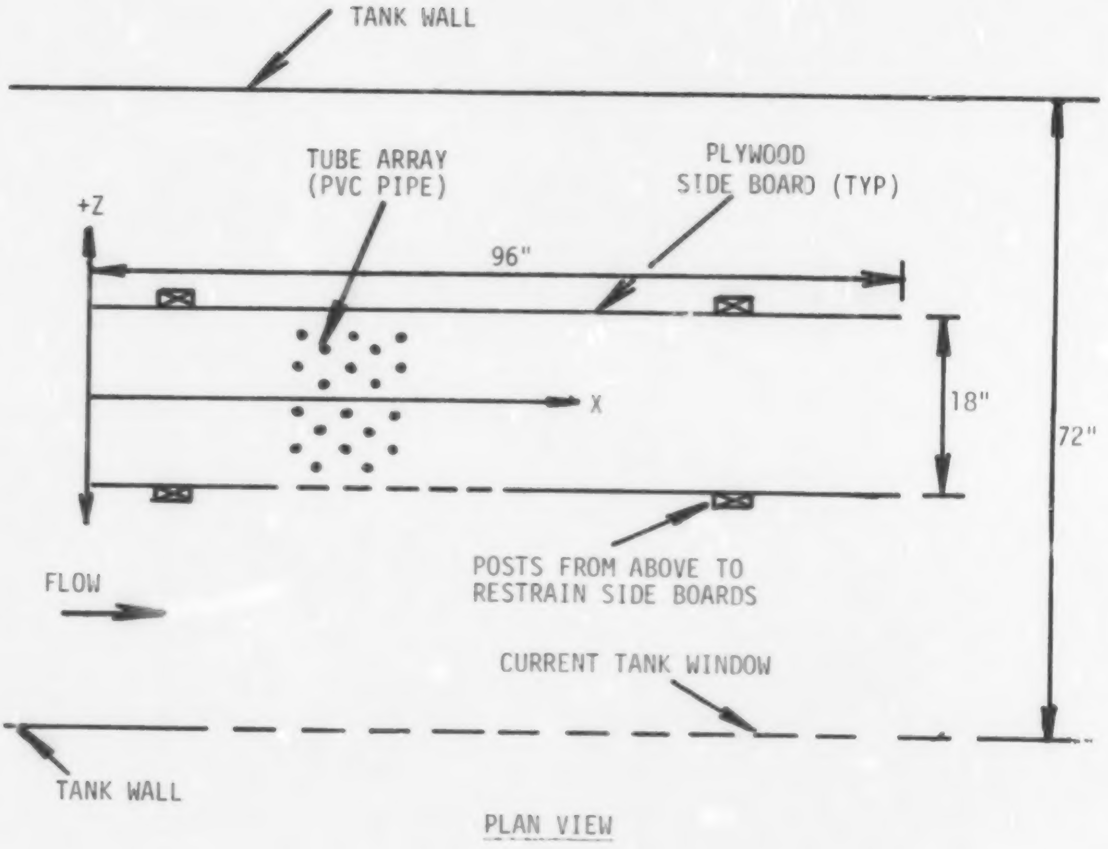
a) The tubes for row X_1 were absent in these runs and the row for X_2 is vertical.

b) Inclined tubes were not used.

c) Board placed between X_1 and X_2 in a horizontal position.


TANK WALL
TUBE ARRAY
(PVC PIPE)
PLYWOOD
SIDE BOARD (TYP)
+Z
96"
X
18"
72"
POSTS FROM ABOVE TO
RESTRAIN SIDE BOARDS
FLOW
CURRENT TANK WINDOW
TANK WALL
PLAN VIEW

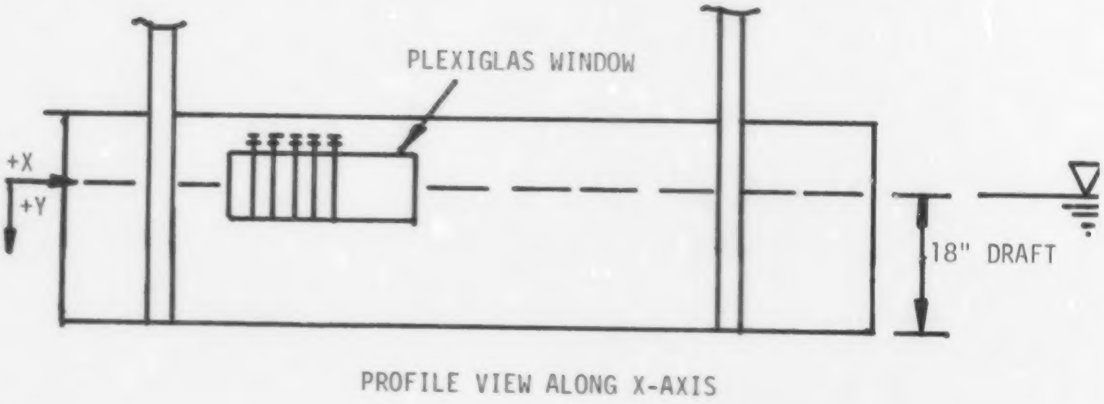

PLEXIGLAS WINDOW
+X
+Y
18" DRAFT
PROFILE VIEW ALONG X-AXIS

FIGURE A-1 - SKETCH OF STUB-TUBE ARRAY BAFFLE TEST CONFIGURATIONS FOR TESTS SM-1 THROUGH SM-11. (SIDE BOARDS PREVENT 3D EFFECTS.)

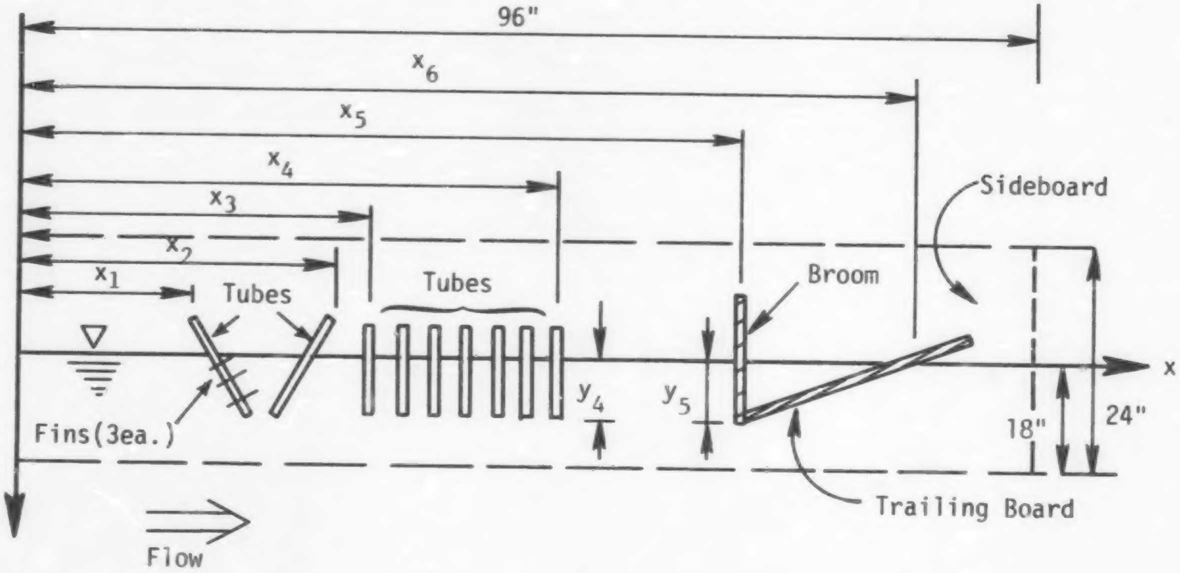

96"
x_6
x_5
x_4
x_3
x_2
x_1
Sideboard
Broom
Tubes
Tubes
Fins(3ea.)
y_4
y_5
18"
24"
x
Trailing Board
Flow

FIGURE A-2 - SKETCH OF STUB-TUBE BAFFLE TEST CONFIGURATION FOR TESTS SM-12 THROUGH SM-31. (SIDE BOARDS PREVENT 3D EFFECT)

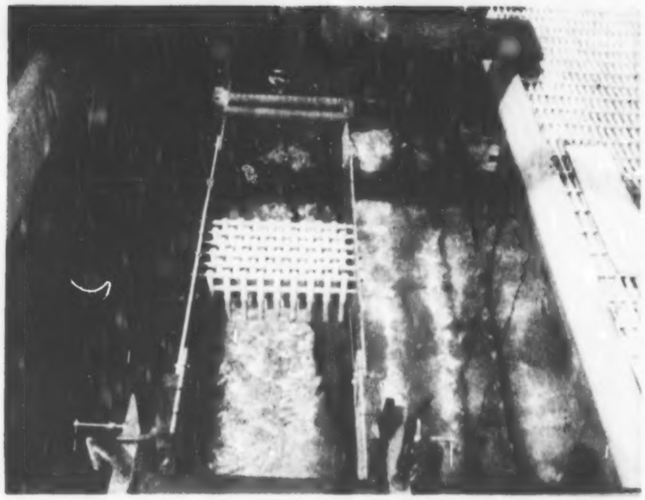


FIGURE A-3 - SM-1; 1.05 FPS .84" OD TUBES

FIGURE A-4 - TEST SM-1; 1.05 FPS

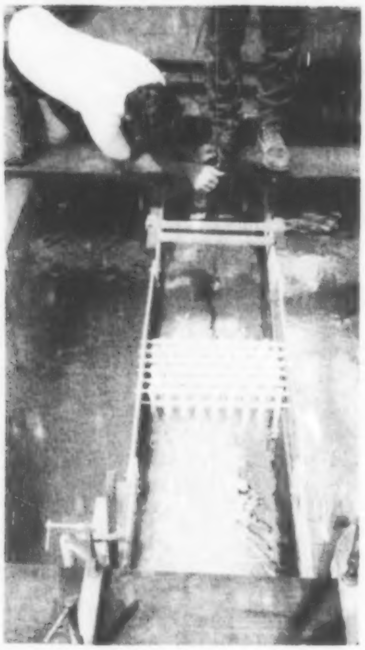


FIGURE A-5 - TEST SM-1; 1.05 FPS

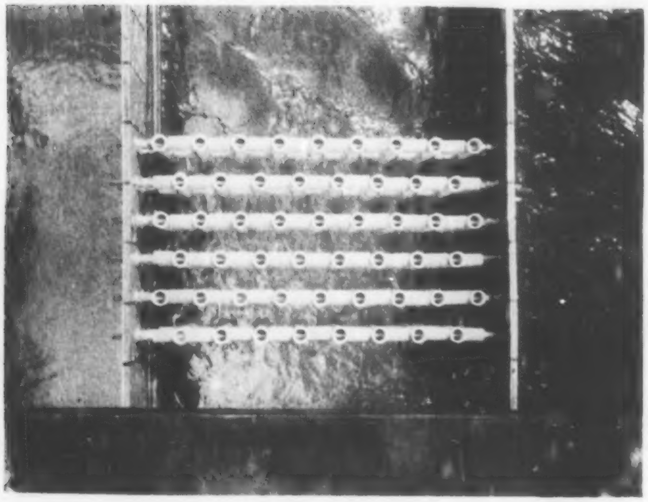


FIGURE A-6 - TEST SM-2; 2.1 FPS

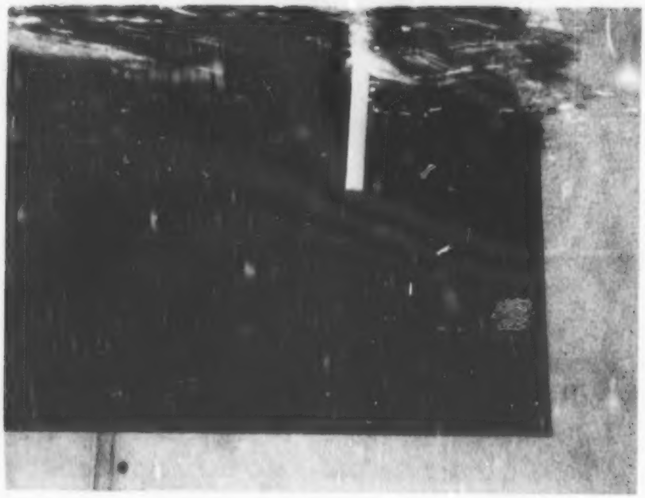


FIGURE A-7 - SINGLE TUBE HAND HELD OBSERVATIONS

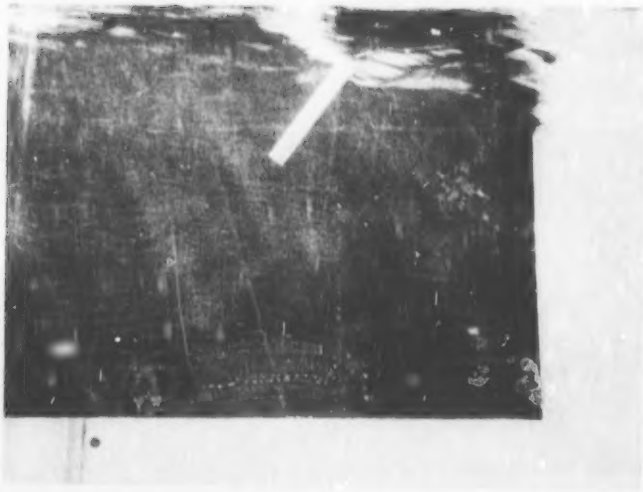


FIGURE A-8 - SINGLE TUBE UPSTREAM ANGLE (35°)

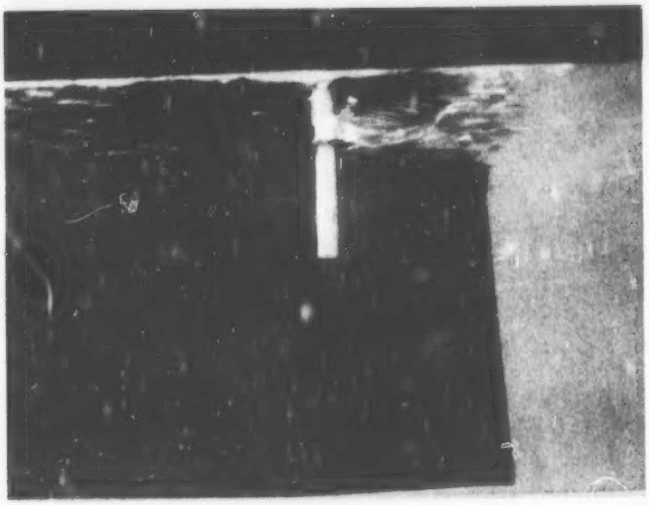


FIGURE A-9 - SINGLE TUBE WITH FIN 1" DEEP, NO VORTICES

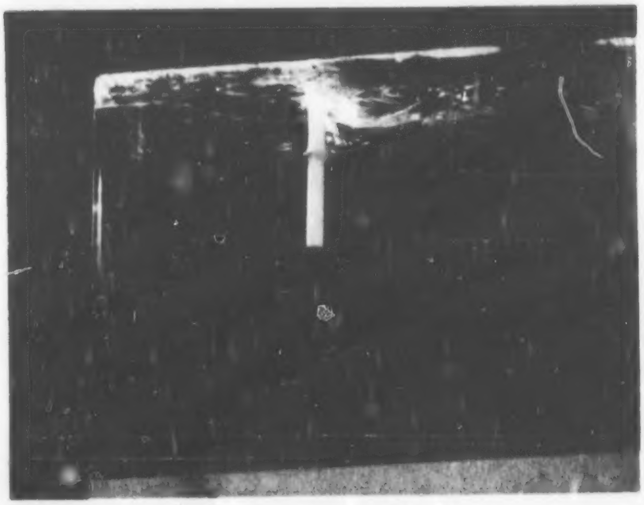


FIGURE A-10 - SINGLE TUBE WITH FIN, TWO INCHES DEEP, VORTICES APPEARING

FIGURE A-11 - SINGLE ROW OF TUBES IN FREE STREAM, VORTICES

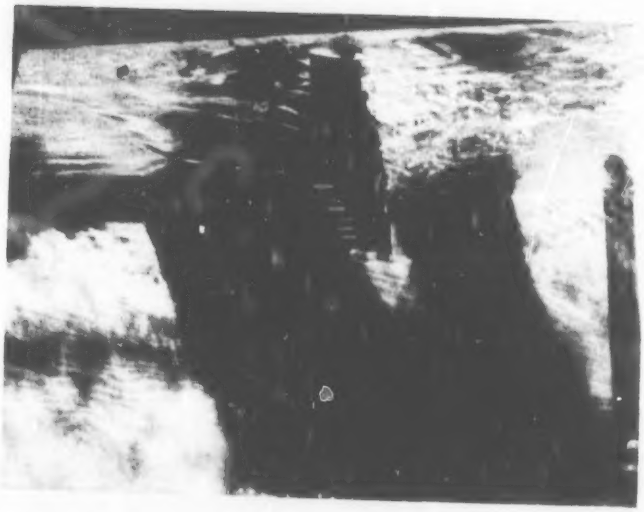


FIGURE A-12 - SINGLE ROW OF TUBES WITH STREAMERS, VORTICES

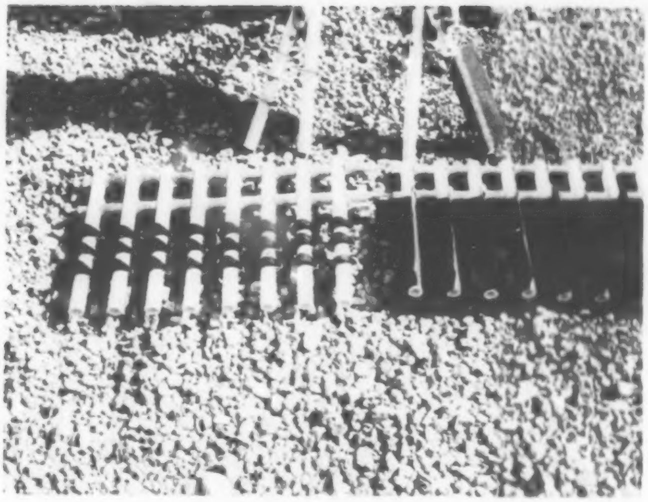


FIGURE A-13 - TOP ROW, LEFT TO RIGHT: TUBE WITH 3 FINS, TUBE WITH SINGLE FIN, TUBE (ONLY). TUBE WITH STREAMER. SECOND ROW: ROW OF TUBES WITH FINS, ROW OF TUBES WITH STREAMER

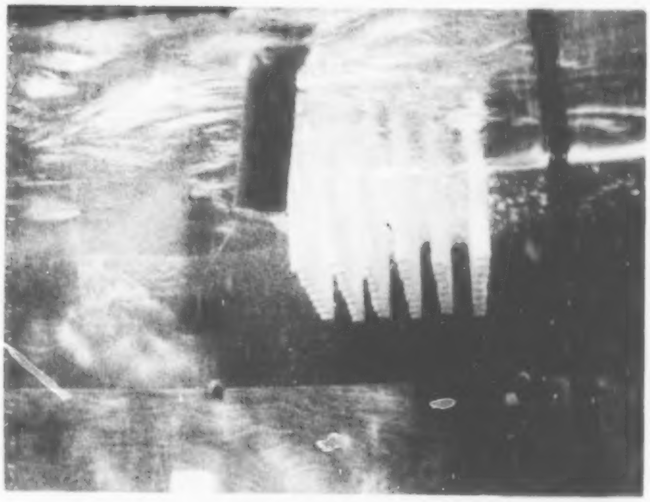


FIGURE A-14 - SINGLE TUBE WITH STREAMER, NO VORTICES

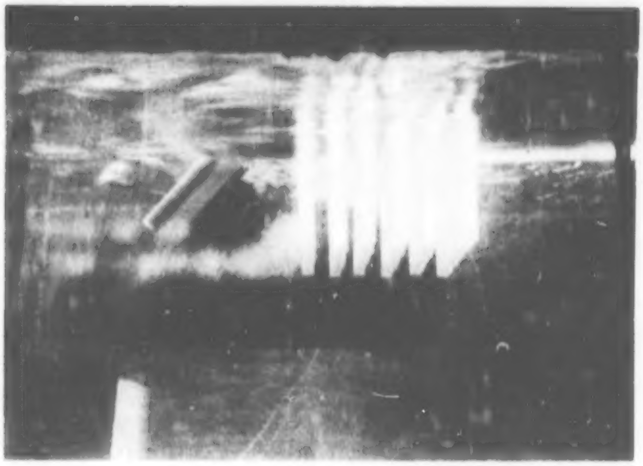


FIGURE A-15 - ROW OF TUBES WITH STREAMERS IN AN UPSTREAM ANGLE IN FRONT OF 6 ROWS ON 2" ℄ TO ℄

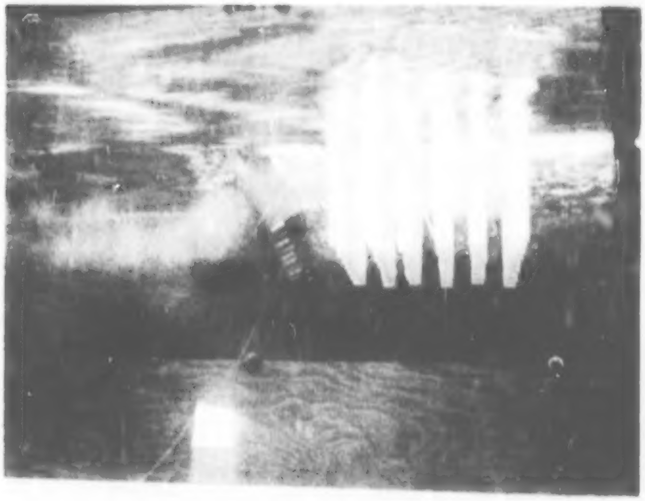


FIGURE A-16 - AS ABOVE ONLY DOWNSTREAM ANGLE

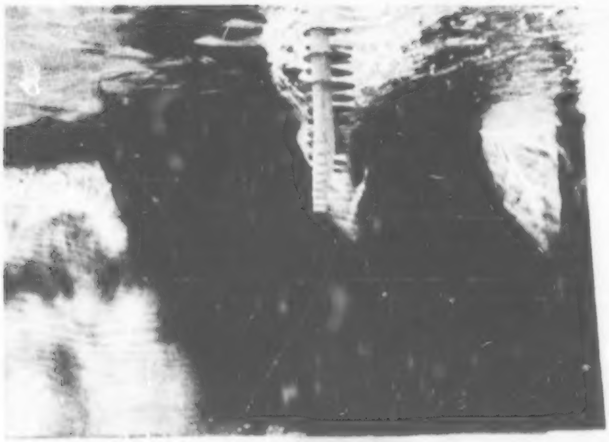


FIGURE A-17 - SINGLE ROW OF TUBES WITH FINS IN FREE STREAM - VERY LITTLE TURBULENCE

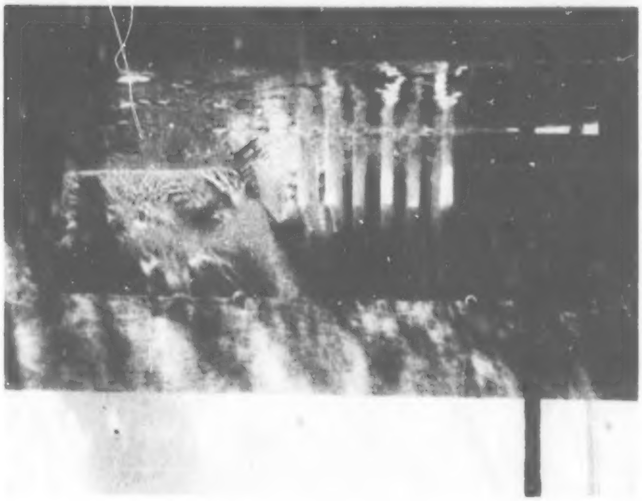


FIGURE A-18 - ROW OF TUBES WITH FINS AT A DOWNSTREAM ANGLE

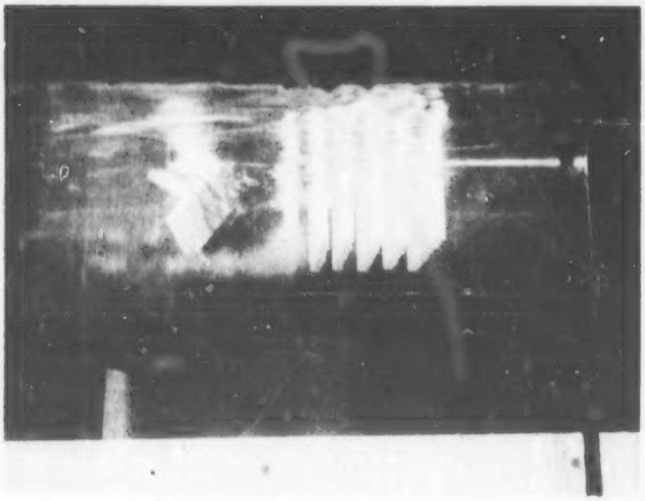


FIGURE A-19 - ROW OF TUBES WITH FINS, UPSTREAM ANGLE

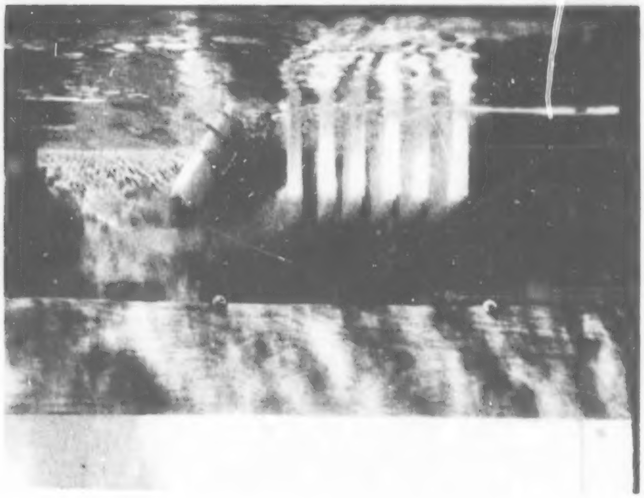


FIGURE A-20 - SAME AS ABOVE ONLY DEEPEN DRAFT

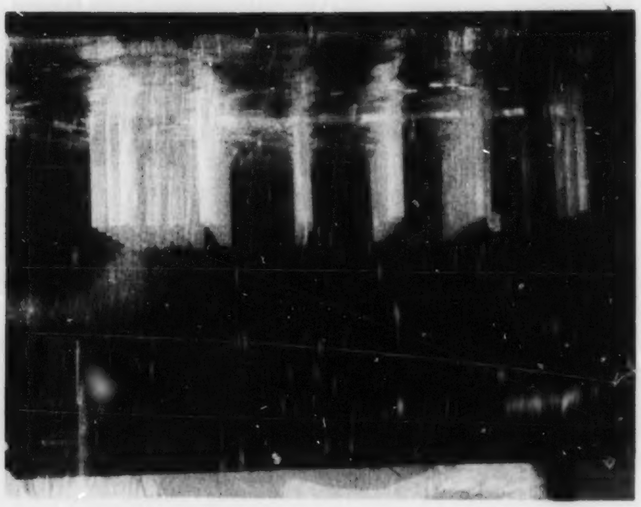


FIGURE A-21 - TEST SM-7, 2.15 FPS

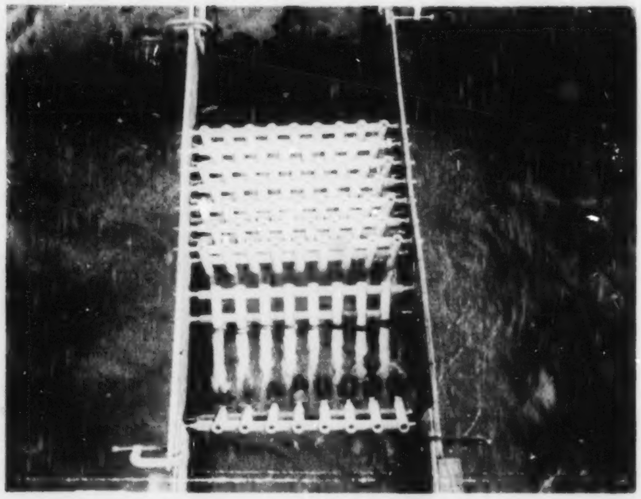


FIGURE A-22 - TEST SM-8, 2.1 FPS

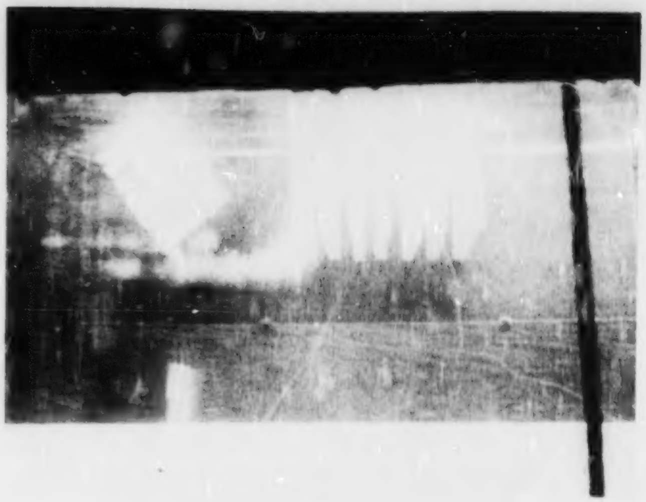


FIGURE A-23 - TEST SM-8, 2.1 FPS

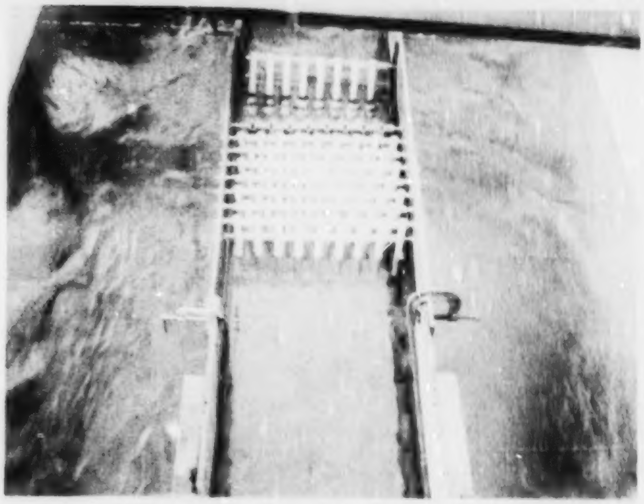


FIGURE A-24 - TEST SM-8, 2.1 FPS

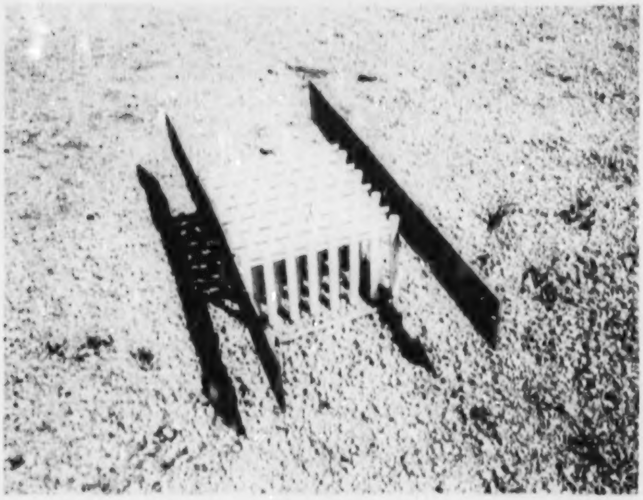


FIGURE A-25 - SM-9, ARRAY OF 1.076" OD TUBES

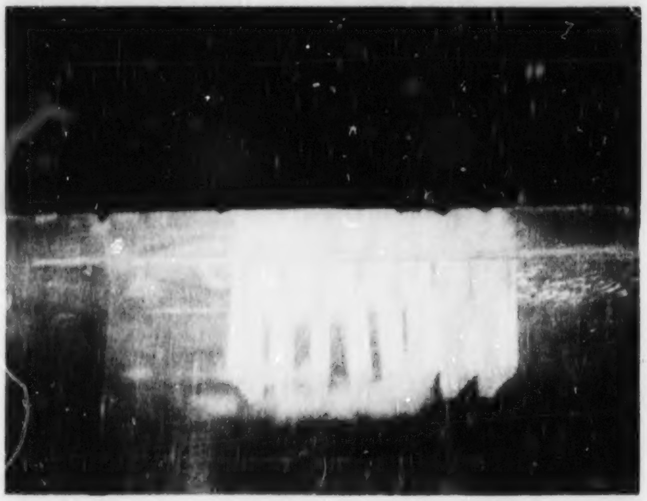


FIGURE A-26 - SM-9, 1.95 FPS

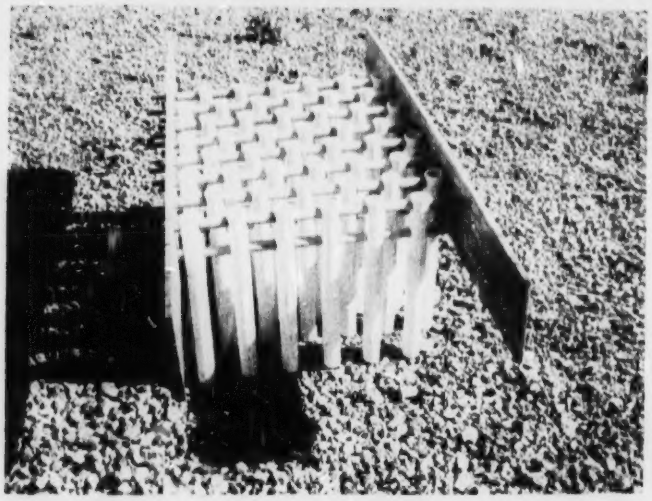


FIGURE A-27 - 1.314" OD TUBES USED FOR TEST 10 AND 11

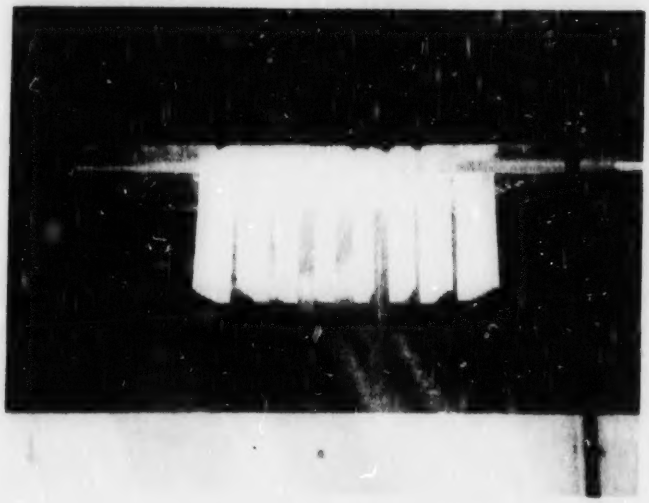


FIGURE A-28 - SM 10, 2.05 FPS

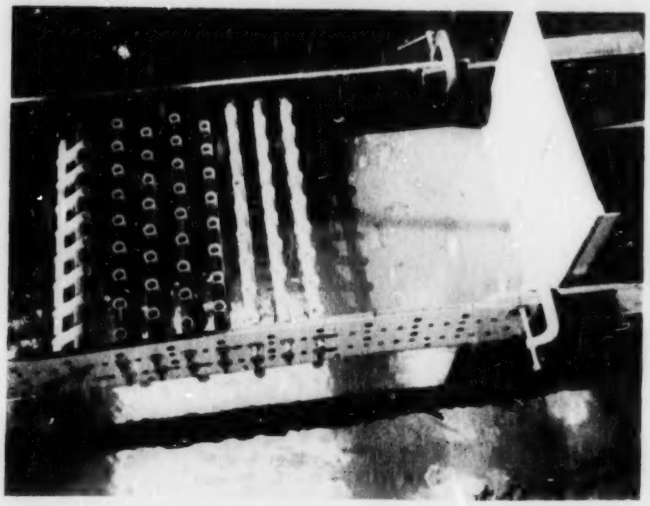


FIGURE A-29 - TEST SM-12, 1.05 FPS
BOOM 15 INCHES BEHIND BOOM

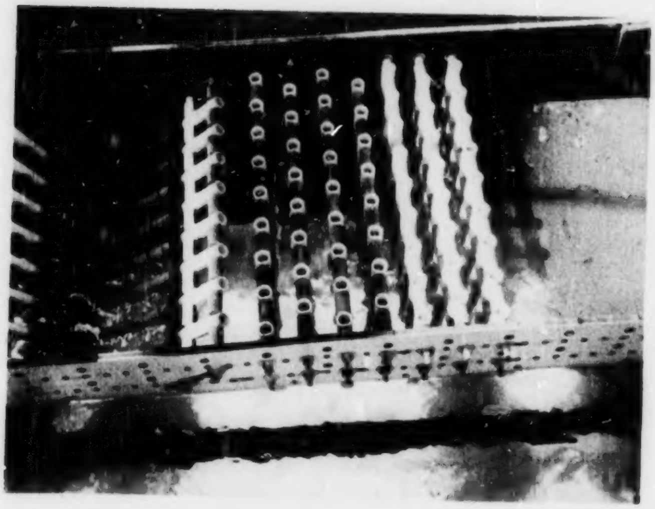


FIGURE A-30 - TEST SM-12, 1.05 FPS

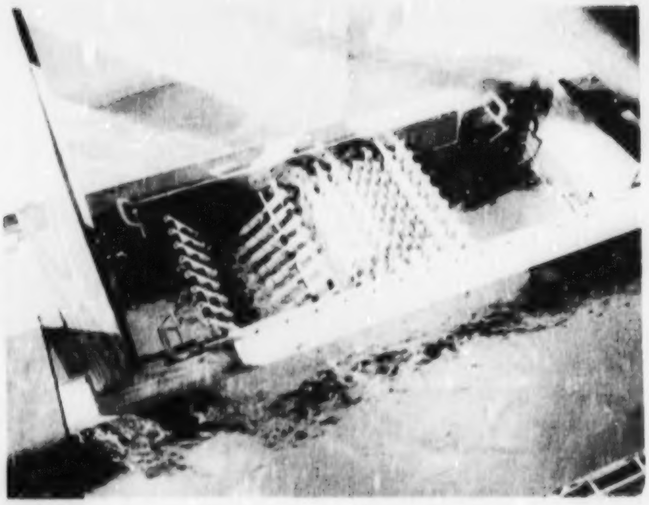


FIGURE A-31 - TEST SM-24, BOOM 6" DEEP, 3.9 FPS

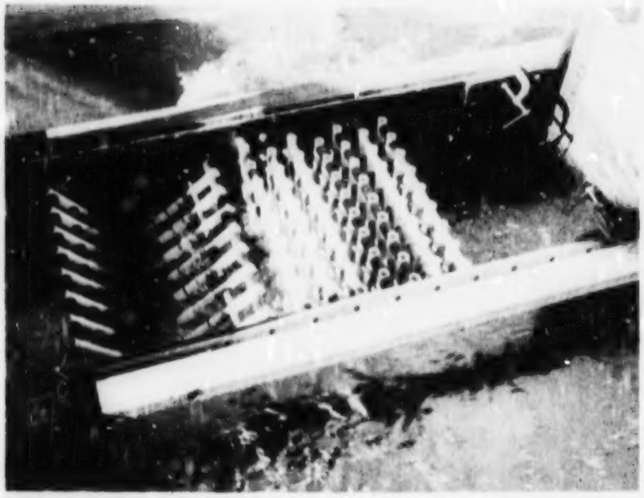


FIGURE A-32 - TEST SM-24, BOOM 3" DEEP, 3.9 FPS

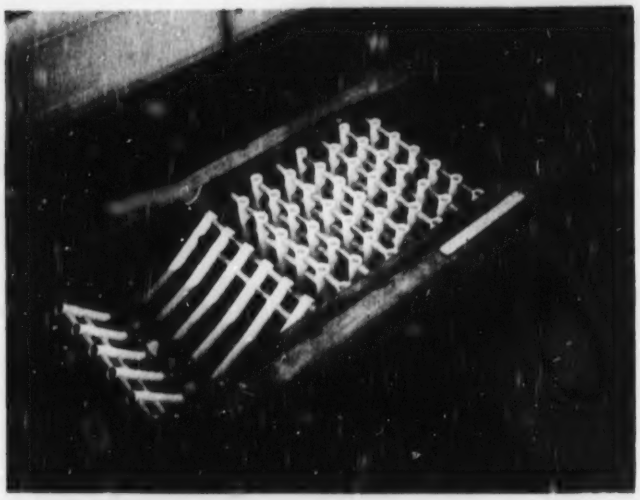


FIGURE A-33 - TEST SM-28, 8.25" DRAFT ON TUBES

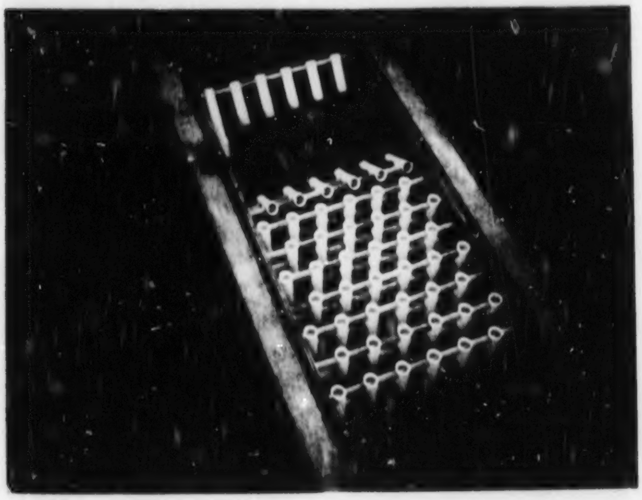


FIGURE A-34 - TEST SM-31, HORIZONTAL BOARD IN PLACE, 9.4-INCH TUBE DRAFT

APPENDIX B

DETAILS OF PERFORATED-PLATE BAFFLE EXPERIMENTS

(IPM 1 through IPM 33)

CONFIGURATION STUDIES

A detailed step-by-step summary of the individual inclined, perforated plate baffle experiments run in the Shell Current Tank is found in Table B-1. Figure B-1 shows the configuration profiles and Tables B-2 and B-3 contain the principal dimensions. Figures B-2 through B-32 are selected protographs taken at various stages of experimentation.

FLOW ANALYSIS - FINAL CONFIGURATION

At the conclusion of the model tests a detailed flow analysis of the inclined plate profile (see Figure B-33) was made. A Thermo Science Incorporated (TSI) hot wire anemometer probe was used to measure discrete points in the velocity field caused by the boom profile. In this current tank test the free-stream velocity was set at 4.8 fps (2.8 knots). The TSI probe was placed at predetermined points to measure the velocity. Figure B-34 shows the measured points on the profile found by passing a vertical plane through the boom such that the plate is parallel to the free-stream current vector. Figure B-35 contains measurements taken on a horizontal plane three inches below the water's surface.

Point velocities shown in the two figures indicate that the effect of the two perforated, inclined plates is that of creating a low velocity region just in front of the aft barrier. Variations in readings where symmetry should show identical results can be explained by flow variations and surges in the test tank.

TABLE B-1

SUMMARY OF PERFORATED-PLATE BAFFLE TESTS

Test No.	% Open	Angle of Plate	Front of Plate x = in.	Back of Plate x = in.	Draft of Plate y = in.	Ref. Vel. fps	Vel. x = 0 fps	Vel. x/fps in./fps	Boom Location/Draft in./in.	See Figure	Remarks	Decisions
IPM-1A	46%	18°	39	69	10	2.20	2.21	87/1.65	-	1-7	Only 25% reduction in current.	Reduce open area.
IPM-1B	18.8%	18°	39	69	10	2.20	2.21	87/.47	-	8,9	Observed some ventilation but would not retain beads well.	Place board @ waterline to reduce ventilation.
IPM-1C	18.8%	18°	39	69	10	2.20	2.21	87/.24	-	10,11	Stops ventilation but would not retain beads well.	Try open-bottomed coke crate without board. Also insert rear barrier.
IPM-2A	18.8%	18°	39	69	10	2.25	-	-	69/10		Used coke box; surface of H_2O turbulent but no loss of beads.	Use board rather than coke case, because less surface turbulence occurs.
IPM-2B	18.8%	18°	39	69	10	2.25	-	-	69/10		Used board covering 1st 12 inches of holes; corner vortices formed and beads were lost.	Look at ventilation on upper part of inclined plate without board but with barrier. Try rear barrier further back.
IPM-3	18.8%	18°	39	69	10	2.25	2.26	63/.21	71/10	12	Did not lose plastic beads.	Try rear barrier further back.
IPM-4	18.8%	18°	39	69	10	2.25	2.26	78/.48	84/10	13	Vortices formed in front of barrier.	Move rear barrier further back.
IPM-5	18.8%	18°	39	69	10	2.25	2.26	-	96/6		Occasional vortices formed, occasional loss of beads at 6" draft.	Try the anti-ventilation board again.
IPM-6	18.8%	18°	39	69	10	2.25	-	-	69/10		Some of the board were lost.	Try coke box again.
IPM-7	18.8%	18°	39	69	10	2.25	-	-	78/10	14,15	Used coke box arrangement; lots of turbulence.	Use smaller angle for inclined plate; no plate.
IPM-8	18.8%	11	26	69	9	2.25	2.28	42/.67	69/9	16,17	No ventilation; no beads lost.	Try higher velocity.
IMP-9	18.8%	11	26	69	9	3.0	2.80	48/.59	69/9	18,19	Did not lose beads; 79% reduction in velocity.	Try higher velocity.

NOTE: See Figure B-1 and Table B-2 for test configuration and dimensions.

TABLE B-1

SUMMARY OF PERFORATED-PLATE BAFFLE TESTS (Continued)

Test No.	Plate % Open #1/#2	Angle of Plate #1/#2	Front of Plate #1/#2	Back of Plate #1/#2	Draft of Plate #1/#2	Ref. Vel.	Vel. x = 0	Vel. x/fps	Boom Location/ Draft	No. of Plate Sets	Position of Plates	See Figure	Remarks
IPM-10	18.8/-	12°/-	21/-	67/-	12/-	3.75		67/.90	117/6	1	V		Calm in front of barrier; 80% of beads retained.
11	18.8/-	12°/-	21/-	67/-	12/-	3.75			105/6-11	1	V		Barrier at 10" too deep, causing too much back flow. Barrier at 6" eliminates most of the back flow. Try moving closer.
12	18.8/-	12°/-	21/-	67/-	12/-	3.75			93/6-11	1	V		Caused increased flow upstream in front of boom. Try moving barrier closer yet.
13	18.8/-	12°/-	21/-	67/-	12/-	3.75			81/6-11	1	V		Boom too close; lost most of beads. Try too inclined plates.
14	46/18.8	16°/13°	18/36	63/83	13/10	3.75			105/12	2	V	20	Too much ventilation; lost beads; too much flow.
15	18.8/18.8	16°/18°	18/53	63/96	13/13	3.75		105/.14	120/10	2	V	21	Reduce current flow; collected beads. Try opening forward plate.
15A	46/18.8	16°/18°	18/53	63/96	13/13	3.75		105/.28	120/10	2	V		Too much turbulence with 46% open area in Plate 1. Try another plate orientation—invert Plate 2.
16	18.8/18.8	15°/-12°	18/60	63/102	12/9	3.75			115/6	2	V	22	Would not hold beads in front of barrier. Try inverting both plates.
17	46/18.8	16°/19°	15/72	60/107	13/12	3175			117/10	2	V	23	Too much ventilation between sets of plates; would not collect beads. Try deeper draft barrier.
18	18.8/18.8	16°/19°	15/72	60/107	13/12	3.75			117/12	2	V		Same problems. Try another way.
19	18.8/18.8	16°/19°	15/60	60/95	13/12	3.75	3.37	102/.45	117/12	2	V	24	Same problems. Try another configuration.

NOTE: See Figure B-1 and Table B-3 for test configuration and dimensions.

TABLE B-1

SUMMARY OF PERFORATED-PLATE BAFFLE TESTS (Continued)

Test No.	Plate % Open #1/#2	Angle of Plate #1/#2	Front of Plate #1/#2	Back of Plate #1/#2	Draft of Plate #1/#2	Ref. Vel.	Vel. x = 0	Vel. x/fps	Boom Location/ Draft	No. of Plate Sets	Position of Plates	See Figure	Remarks
20	46/18.8	19°/20°	18/28	60/75	14.5/17.5	3.75			102/10	2	V	25,26	Causes water to fall; beads are lost and turbulence is severe: would likely cause emulsions. Change configuration.
21	18.8/18.8	18°/13°	21/48	63/95	13/11	3.75	3.93		108/10	2	V	27	Antiventilation board held in place eliminates most ventilation.
22	46/18.8	18°/13°	21/48	63/95	13/11	3.75			107/10	2	V		Barrier 10" deep causes too much current action in front of boom.
22A	46/18.8	18°/13°	21/48	63/95	13/11	3.75			117/10	2	V		Better condition with barrier further back; better with board.
23	19.7/18.8	18°/13°	21/48	63/95	13/11	3.75			117/10	2	V	28	Using board almost all beads were caught.
24	18.8/18.8	18°/13°	21/48	63/95	13/11	3.95			116/11	2	V		Lost most of the beads. Horizontal flow control board was not used.
25	18.8/18.8	18°/13°	21/46	63/95	13/11	3.95			116/11	2	V		Lost most of the beads. Horizontal flow control board was not used.
26	18.8/18.8	19°/16°	17/49	60/95	15/13	3.7			117/11	2	V	29,30	With a set of three boards rather than one, almost all of the beads were retained (95%).
27	18.8/18.8	19°/16°	16/49	60/95	15/13	4.1			117/11	2	V	29,30	With this higher velocity, 90% of all beads were retained.
28	18.8/18.8	19°/16°	17/49	60/95	15/13	4.83		5.04	117/11	2	V		All tests have 3 horizontal boards in place; 80% of beads were retained.
29	18.8/18.8	19°/16°	17/49	60/95	15/13	5.06		5.09	117/11	2	V		A slight increase in velocity caused a 40% loss of beads.

NOTES: (a) Velocity readings taken with an Ott Kempten Current Meter next to Ducted meter at reference point six feet in front of incline plate model.
(b) See Figure B-1 and Table B-3 for test configuration and dimensions.

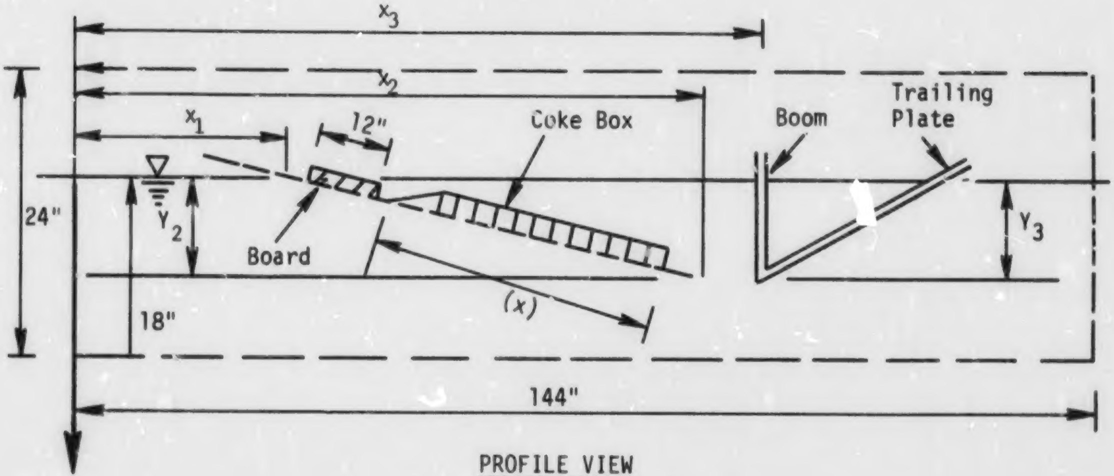
TABLE B-1

SUMMARY OF PERFORATED-PLATE BAFFLE TESTS (Continued)

Test No.	Plate % Open #1/#2	Angle of Plate #1/#2	Front of Plate #1/#2	Back of Plate #1/#2	Draft of Plate #1/#2	Ref. Vel.	Vel. x = 0	Vel.$^{a)}$ x/fps	Boom Location/ Draft	No. of Plate Sets	Position of Plates	See Figure	Remarks
IPM-30	48/18.8	20°/18°	21/54	61/95	15/13	4.72		4.64	117/11	2	V	31	Lost most of the beads. Horizontal flow control board was not used.
31	25/18.8	20°/18°	21/54	61/95	15/13	4.74		4.79	117/11	2	V	32	75% of the beads were retained.
32	18.8/18.8	20°/18°	21/54	61/95	15/13	4.83		4.77	117/11	2	V		75% of the beads were retained.
33	18.8/18.8	20°/18°	21/54	61/95	15/13	4.6		4.77	117/11	2	V		Approximately 80% of all beads were retained by model. Thus tests No.'s IPM-28 and 53 are the best.

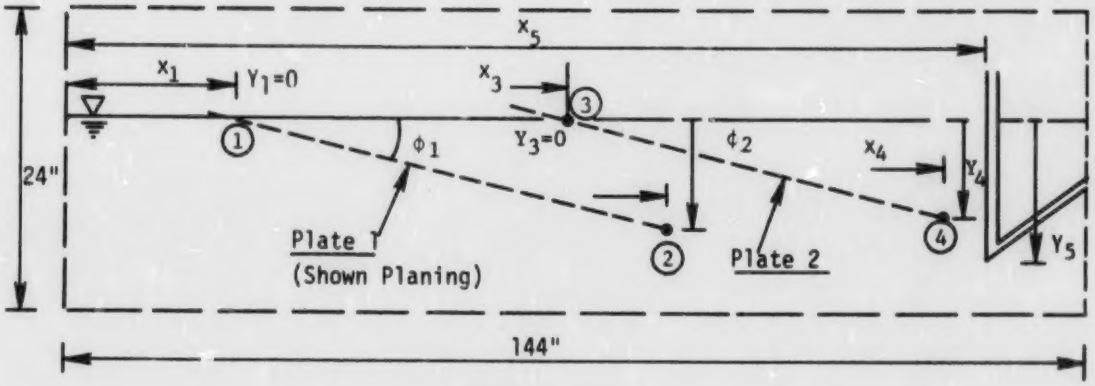
NOTES: (a) Velocity readings taken with an Ott Kempten Current Meter next to Ducted meter at reference point six feet in front of incline plate model.

(b) See Figure B-1 and Table B-3 for test configuration and dimensions.


x_3
x_2
x_1
12"
Coke Box
Boom
Trailing Plate
24"
Y_2
Board
Y_3
(x)
18"
144"

PROFILE VIEW

TESTS IPM-1A THROUGH IPM-9


x_5
x_1
Y_1=0
x_3
③
①
ϕ_1
Y_3=0
ϕ_2
x_4
Y_4
24"
Plate 1
(Shown Planing)
②
Plate 2
④
Y_5
144"

PROFILE VIEW

TESTS IPM-10 THROUGH IPM-33

FIGURE B-1 - SKETCH OF PERFORATED PLATE BAFFLE TEST CONFIGURATIONS
SEE TABLE B-1 FOR SUMMARIZED RESULTS

TABLE B-2

PERFORATED PLATE BAFFLE PRINCIPAL DIMENSIONS TESTS IPM 1 TO IPM 9

Test No.	Vel.	X_1	X_2	X_3	Y_2	Y_3	Plate Angle	% Open Area	Components Used
IPM 1A	2.2	39	69	--	10	--	18°	46	c
1B	2.25	39	69	--	10	--	18°	18.8	c
1C	2.2	39	69	--	10	--	18°	18.8	c,a
2A	2.2	39	69	69	10	10	18°	18.8	b
2B	2.25	39	69	69	10	10	18°	18.8	a
3	2.25	39	69	71	10	10	18°	18.8	
4	2.25	39	69	84	10	10	18°	18.8	
5	2.25	39	69	96	10	6	18°	18.8	
6	2.25	39	69	69	10	10	18°	18.8	a
7	2.25	39	69	79	10	10	18°	18.8	b
8	2.25	26	69	69	9	9	11°	18.8	
9	3.0	26	69	69	9	9	11°	18.8	

---

a) Board was used
b) Coke box was used
c) Boom and trailing plate were not used

TABLE B-3

PERFORATED PLATE BAFFLE PRINCIPAL DIMENSIONS

TESTS IPM-10 TO IPM-33

Test No.	Plate Incli-nations	Coordinates X_1, Y_1 (in.)	X_2, Y_2 (in.)	X_3, Y_3 (in.)	X_4, Y_4 (in.)	ϕ_1* (Deg)	ϕ_2* (Deg)	X_5 (in.)	Y_5 (in.)	% Open Area Plate 1	Plate 2
10	V	21,0	57,10	-	-	12	-	117	6-11	18.8	-
11	V	21,0	67,10	-	-	12	-	105	6-11	18.8	-
12	V	21,0	67,10	-	-	12	-	93	6-11	18.8	-
13	V	21,0	67,10	-	-	12	-	81	6-11	18.8	-
14	V	18,0	63,13	36,0	83,10	16	13	105	12	46.0	18.8
15	V	18,0	63,13	53,0	96,13	16	18	120	10	18.8	18.8
15A	V	18,0	63,13	53,0	96,13	16	18	120	10	46.0	18.8
16	V	18,0	63,12	60,9	102,0	15	12	115	6	18.8	18.8
17	V	15,13	60,0	72,0	107,12	16	19	117	10	46.0	18.8
18	V	15,13	60,0	72,0	107,12	16	19	117	12	18.8	18.8
19	V	15,13	60,0	60,0	95,12	16	19	117	12	18,8	18,8
20	V	18,14.5	60,0	28,17.5	75,0	19	20	102	10	46.0	18.8
21	V	21,0	63,13	48,0	96,11	18	13	108	10	18.8	18.8

---

*ϕ_1 and ϕ_2 are measured from the water line to the plate for both cases (planing or diving).

TABLE B-3 (Continued)

Test No.	Plate Incli- nations	Coordinates								% Open Area	
		X_1, Y_1 (in.)	X_2, Y_2 (in.)	X_3, Y_3 (in.)	X_4, Y_4 (in.)	$\phi 1^*$ (Deg)	$\phi 2^*$ (Deg)	X_5 (in.)	Y_5 (in.)	Plate 1	Plate 2
22	V	21,0	63,13	48,0	95,11	18	13	107	10	46.0	18.8
22*	V	21.0	63,13	48,0	95,11	18	13	117	10	46.0	18.8
23	V	21,0	63,13	48,0	95,11	18	13	117	10		18.8
24	V	21,0	63,13	48,0	95,11	18	13	116	11	18.8	18.8
25	V	21,0	63,13	48,0	95.11	18	13	116	11	18.8	18.8
26	V	17,0	60,15	49,0	95,13	19	16	117	11	18.8	18.8
27	V	17,0	60,15	49,0	95,13	19	16	117	11	18.8	18.8
28	V	17,0	60,15	49,0	95,13	19	16	117	11	18.8	18.8
29	V	17,0	60,15	49,0	95,13	19	16	117	11	18.8	18.8
30	V	21,0	61,15	54,0	95,13	20	18	116	11	48.0	18.8
31	V	21,0	61,15	54,0	95,13	20	18	117	11	25.0	18.8
32	V	21,0	61,15	54,0	95,13	20	18	117	11	18.8	18.8
33	V	21,0	61,15	54,0	95,13	20	18	117	11	18.8	18.8

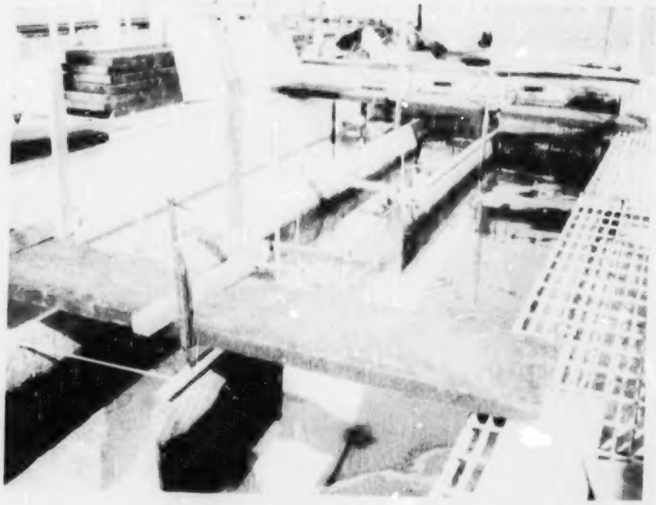


FIGURE B-2 - TEST SETUP, TOP VIEW

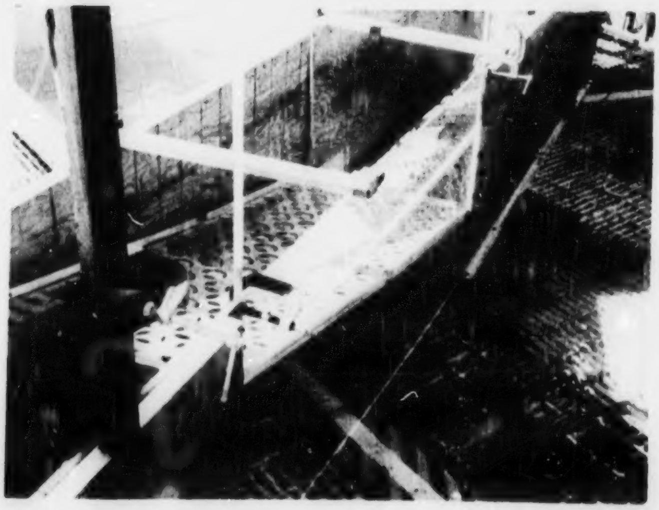


FIGURE B-3 - INCLINED PLATE SETUP, 18.8% OPEN

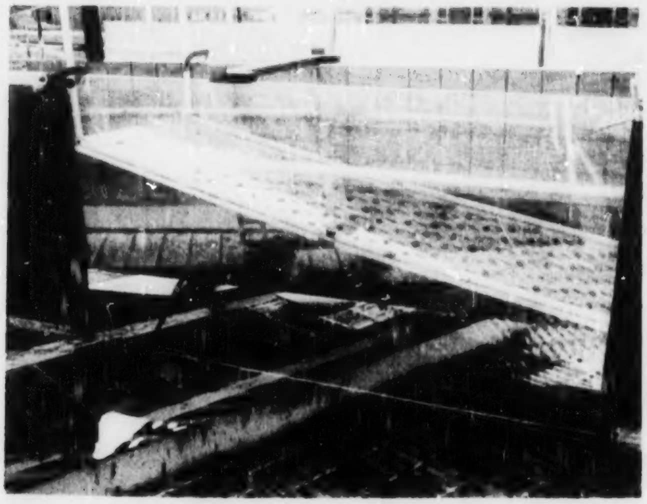


FIGURE B-4 - SIDE VIEW THROUGH TANK WINDOW

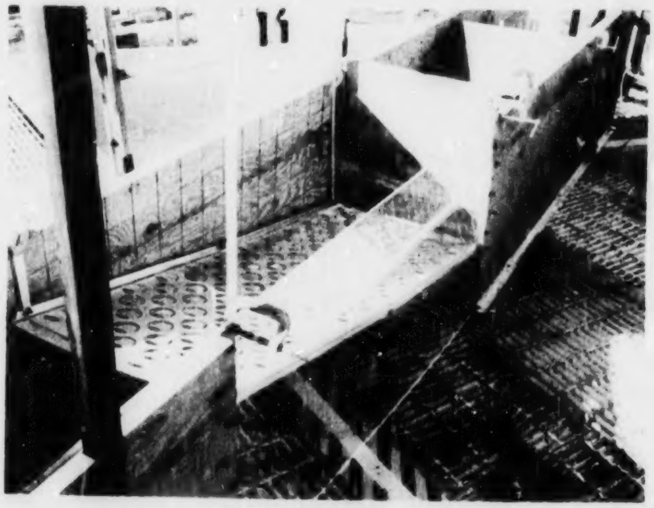


FIGURE B-5 - PERFORATED INCLINED PLATES WITH REAR BOOM

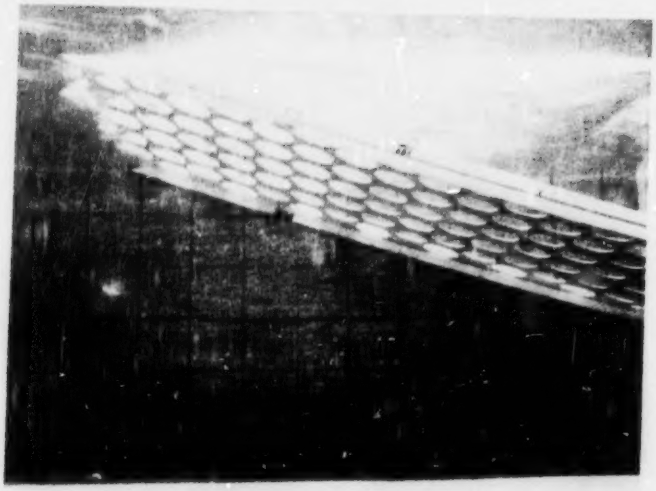


FIGURE B-6 - IPM-1A: SIDE VIEW, 2.2 FPS, 46% OPEN

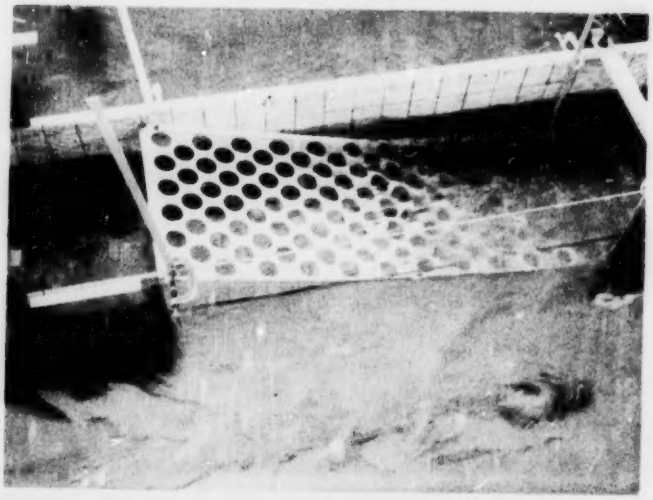


FIGURE B-7 - IPM-1A: TOP VIEW, 46% OPEN, 2.2 FPS

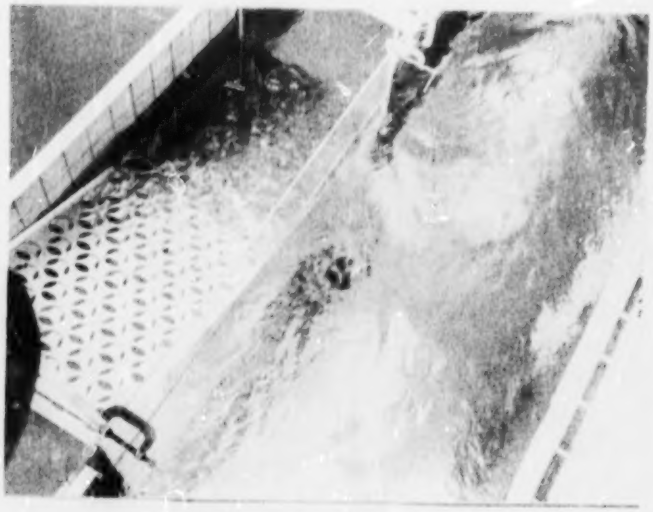


FIGURE B-8 - IPM-1B: TOP VIEW, 18.8% CLOSED, 2.2 FPS

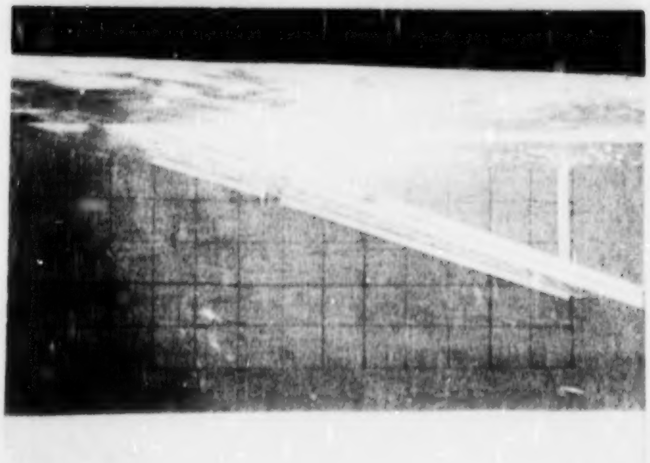


FIGURE B-9 - IPM-1B: SIDE VIEW, 18.8% OPEN, 2.2 FPS, VENTILATION

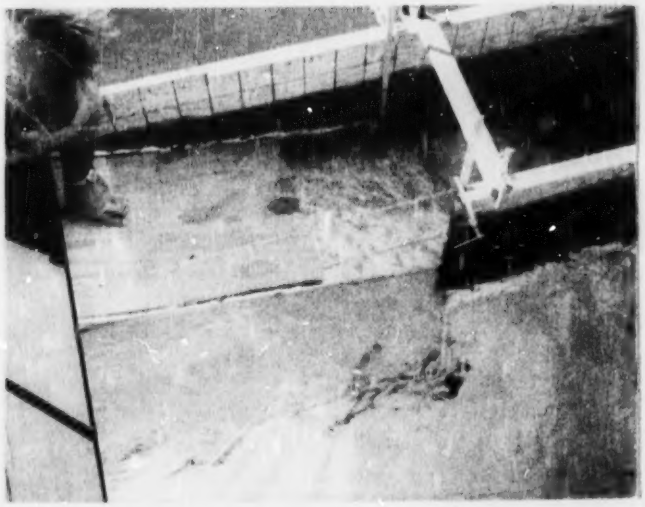


FIGURE B-10 - IPM-1C: ANTIVENTILATION BOARD ON TOP OF PLATES

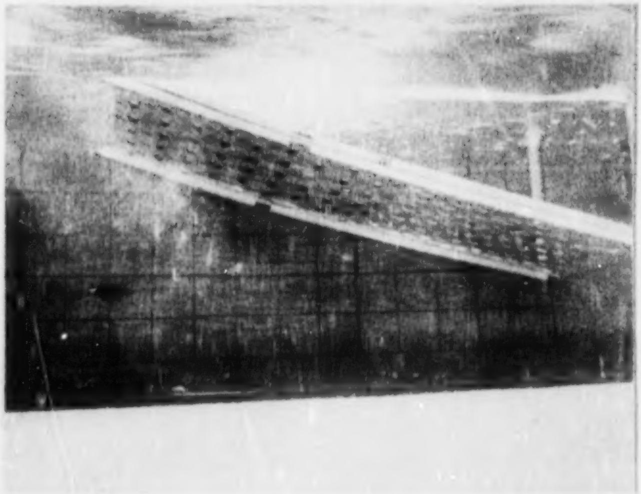


FIGURE B-11 - IPM-1C: 18.8% OPEN, 2.2 FPS

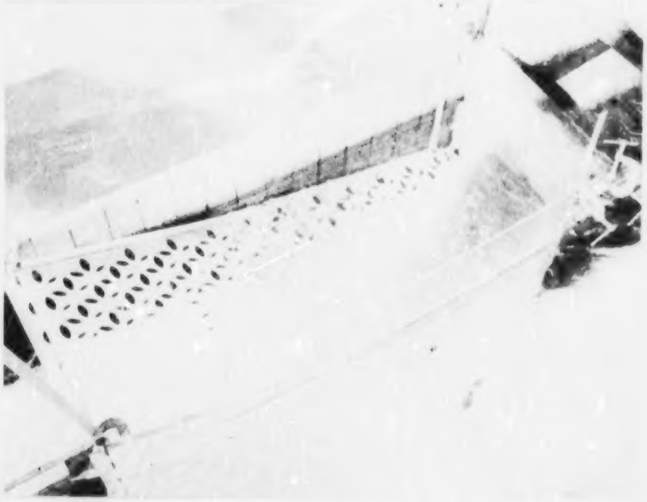


FIGURE B-12 - IPM-3: 18.8% OPEN, 2.25 FPS, BOOM IN PLACE

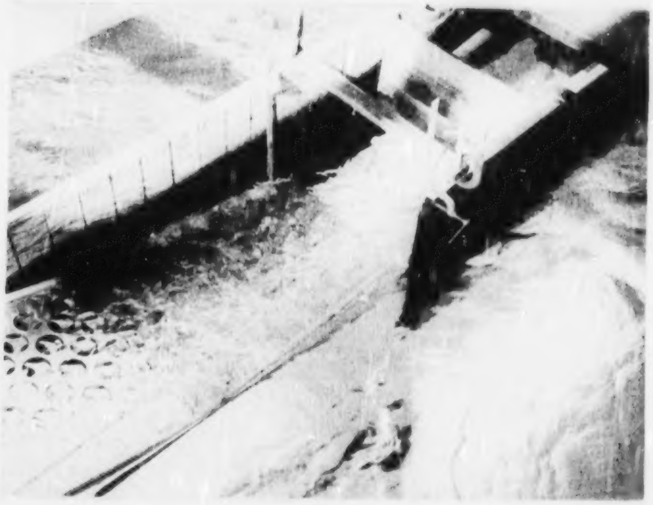


FIGURE B-13 - IPM-4, 18.8% OPEN, 2.25 FPS, BOOM AT X = 84

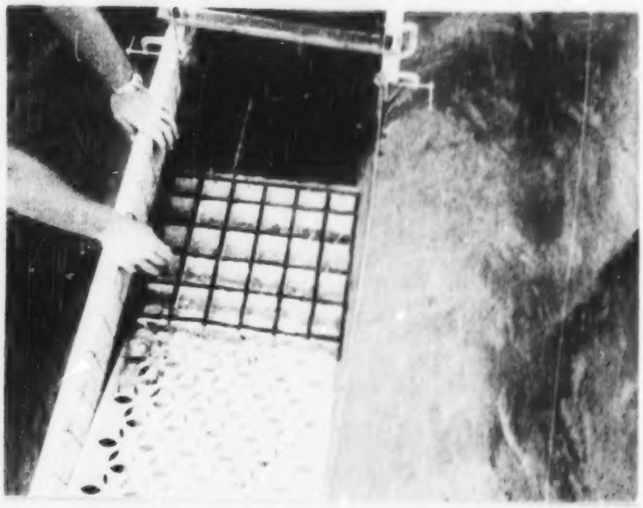


FIGURE B-14 - IPM-7: COKE BOX ARRANGEMENT, NOTICE TURBULENCE; 18.8% OPEN, 2.25 FPS

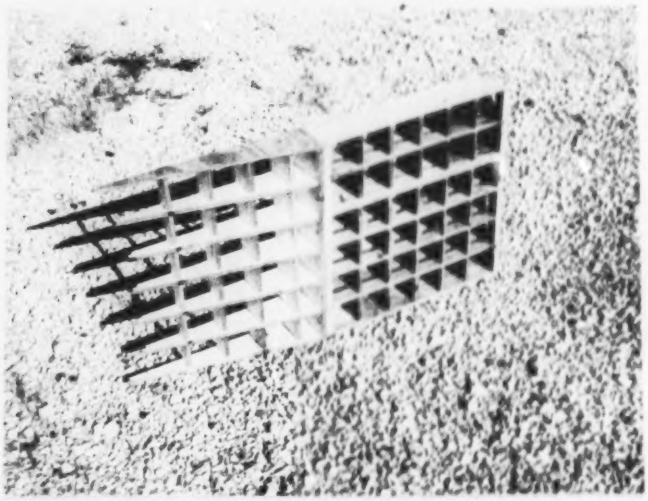


FIGURE B-15 - IPM-7: PHOTO OF COKE BOX ARRANGEMENT

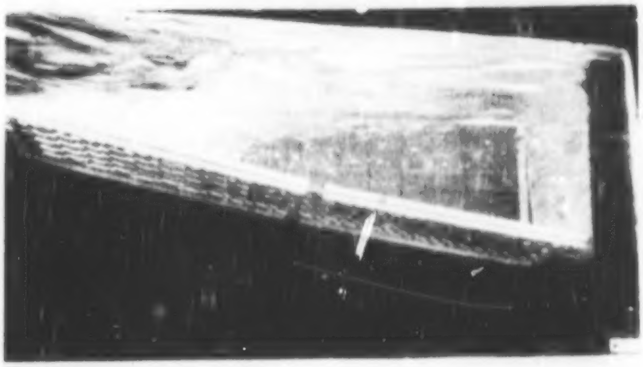


FIGURE B-16 - IPM-8: SIDE VIEW AT 2.25 FPS WITH 18.8% OPEN AREA

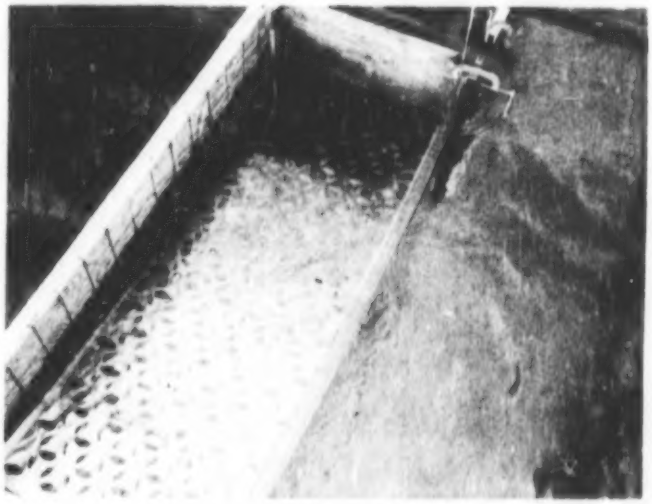


FIGURE B-17 - IPM-8: 18.8% OPEN AREA, 2.25 FPS, BOOM AT END OF PLATE; NOTICE QUIET SURFACE IN FRONT OF THE BOOM

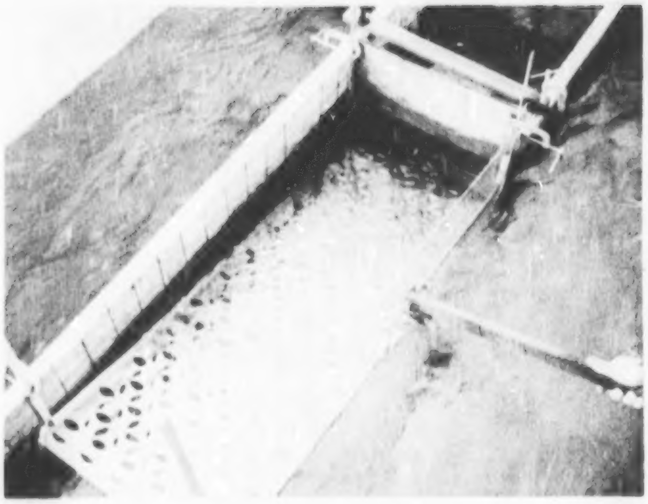


FIGURE B-18 - IPM-9: 3.0 FPS, 18.8% CLOSE, SURFACE OF WATER IS STILL

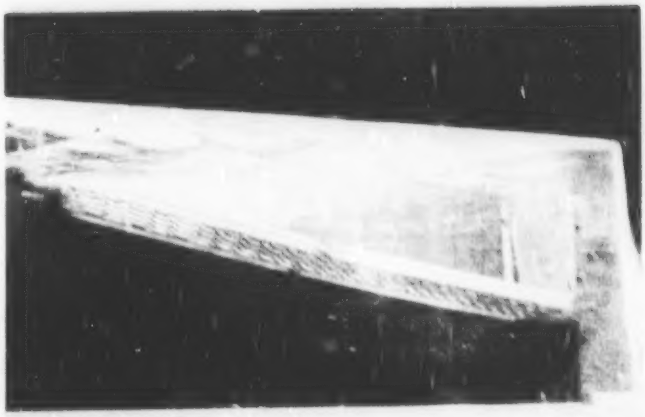


FIGURE B-19 - IPM-9: SIDE VIEW, 18.8% OPEN AREA AT 3.0 FPS

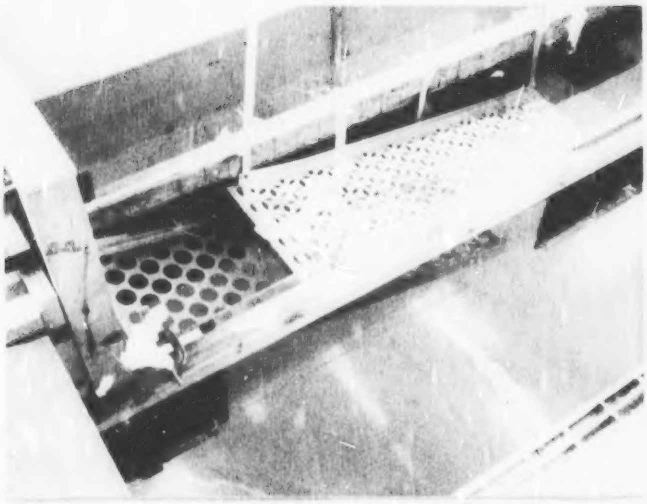


FIGURE B-20 - SET-UP FOR IPM-14, NO CURRENT

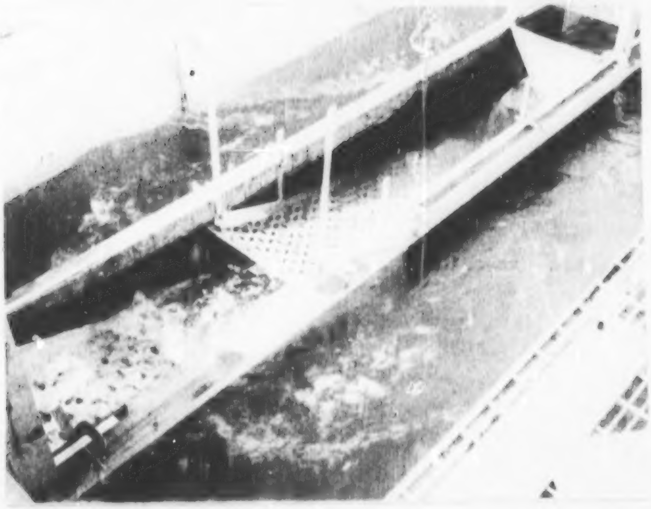


FIGURE B-21 - TEST IPM-15, 3.75 FPS

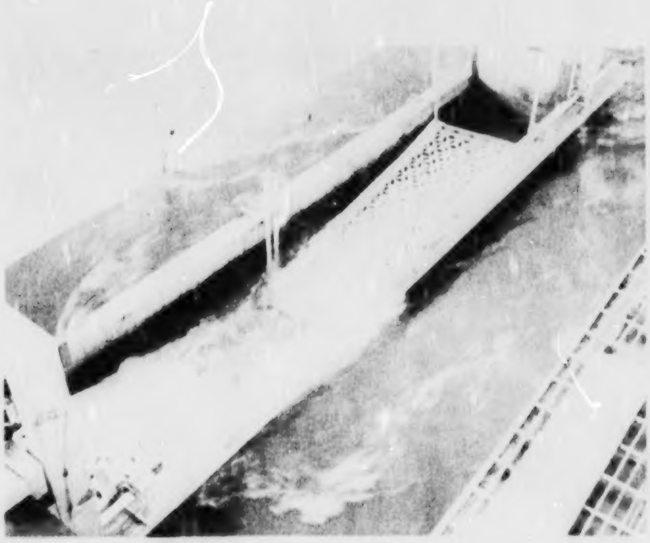


FIGURE B-22 - TEST IPM-16, 3.75 FPS

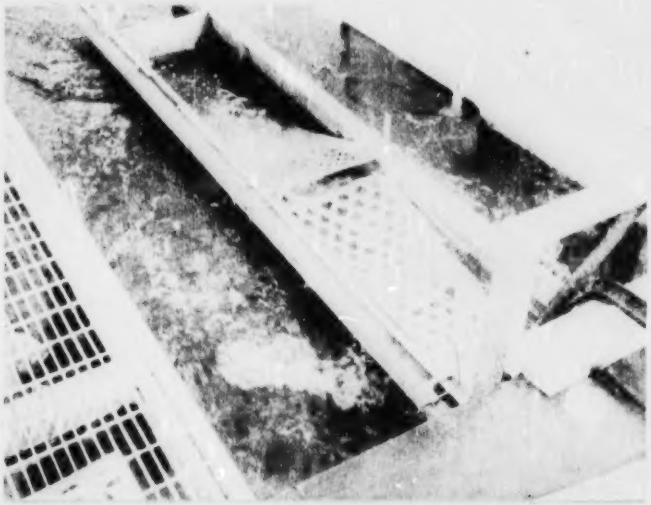


FIGURE B-23 - TEST IPM-17, 3.75 FPS, BOOM 10" DEEP

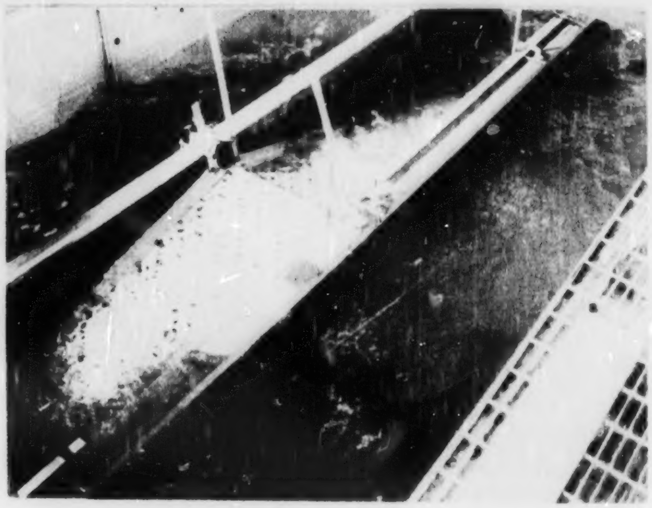


FIGURE B-24 - TEST IMP-19, 3.75 FPS, BOTH PLATES 18.8% OPEN

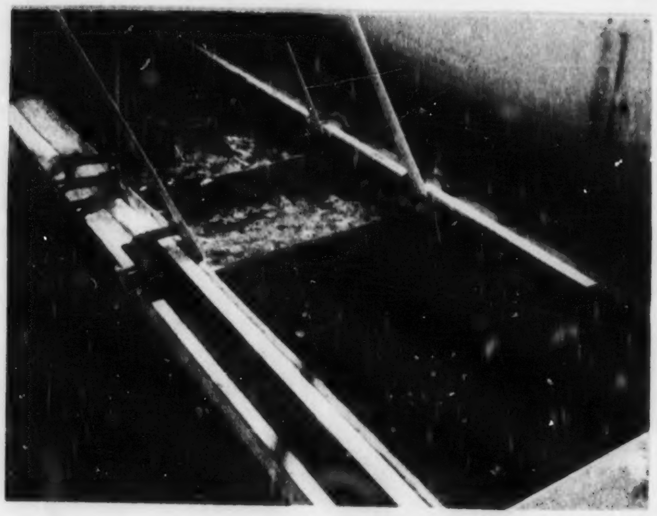


FIGURE B-25 - TEST IPM-20, 3.75 FPS

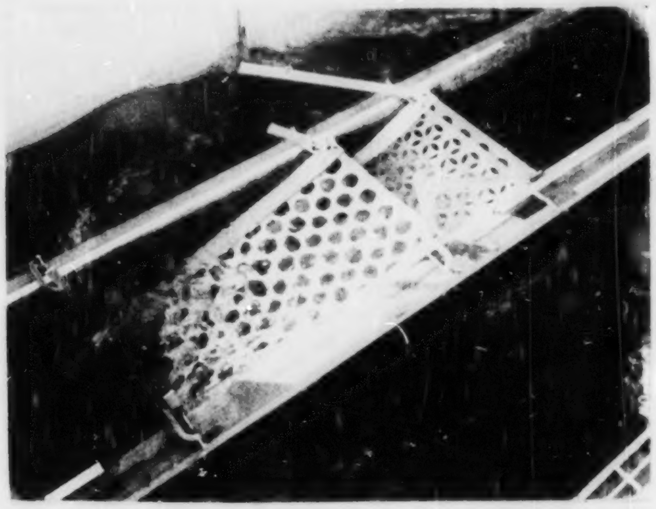


FIGURE B-26 - TEST IPM-20, 3.75 FPS

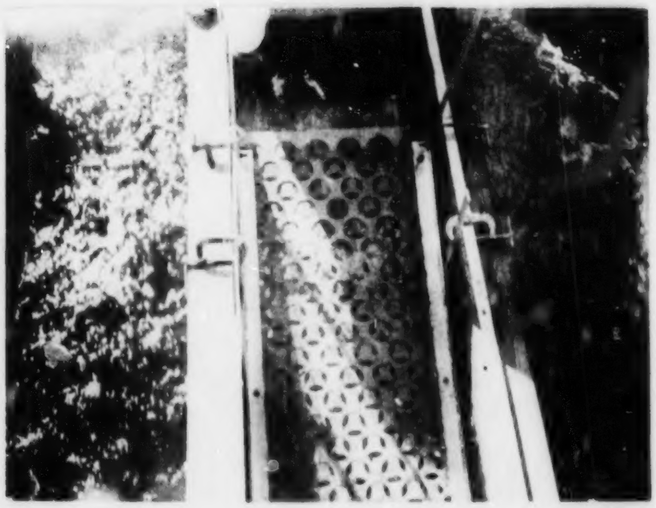


FIGURE B-27 - TEST IPM-21, HAND HOLDING BOARD ON UPSTREAM SET OF PLATES, 3.75 FPS

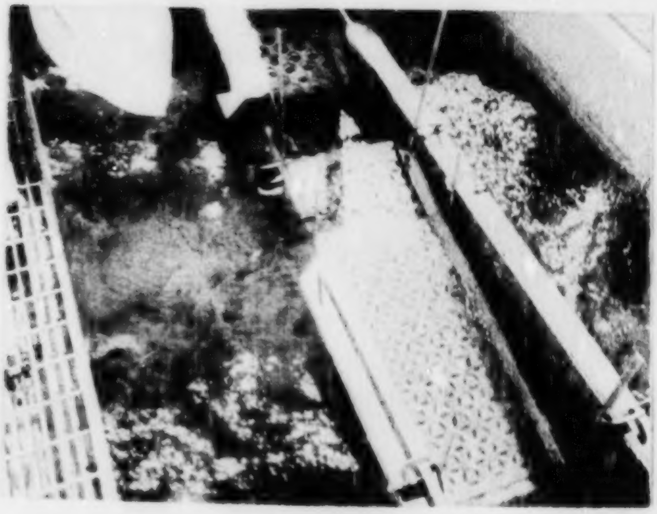


FIGURE B-28 - TEST IPM-23 FPS, HAND-HOLDING BOARD

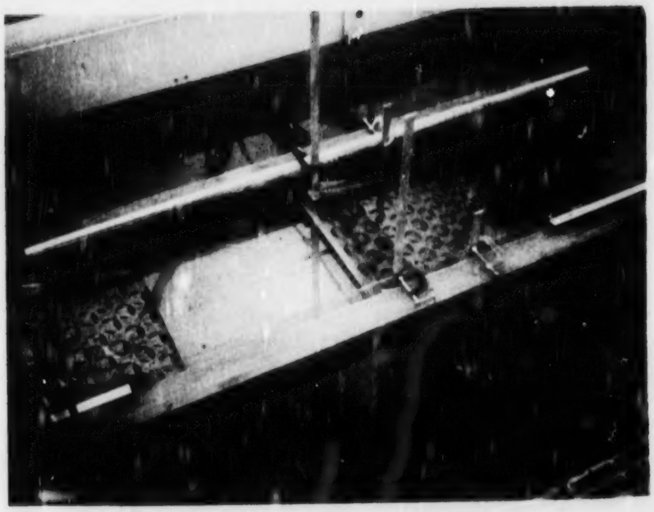


FIGURE B-29 - TESTS 26 AND 27, BOARDS IN PLACE

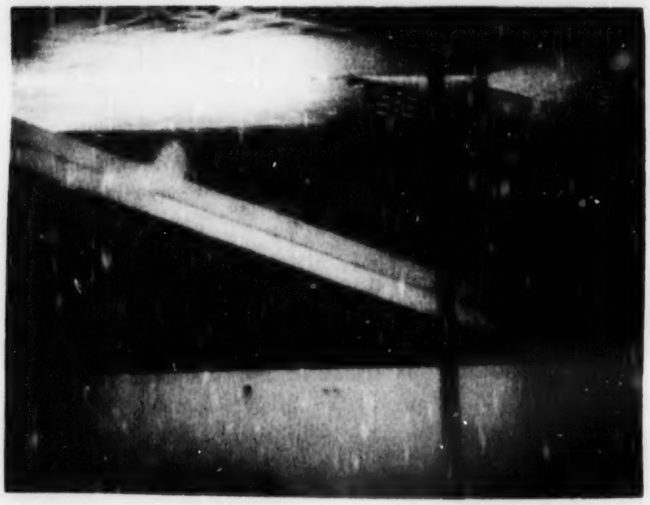


FIGURE B-30 - TESTS 26 and 27, SIDE VIEW

FIGURE B-31 - TEST IPM-30. PLATE 1 IS 48% OPEN AND PLATE 2 IS 18.8% OPEN; THE VELOCITY IS 4.7 FPS

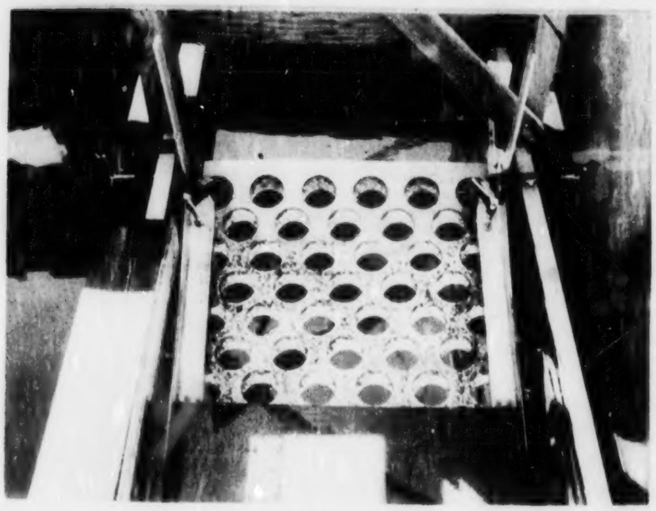


FIGURE B-32 - TEST IPM-31, PLATE 1 IS 25% OPEN AND PLATE 2 IS 18.8% OPEN; THE FREE STREAM VELOCITY IS 4.7 FPS

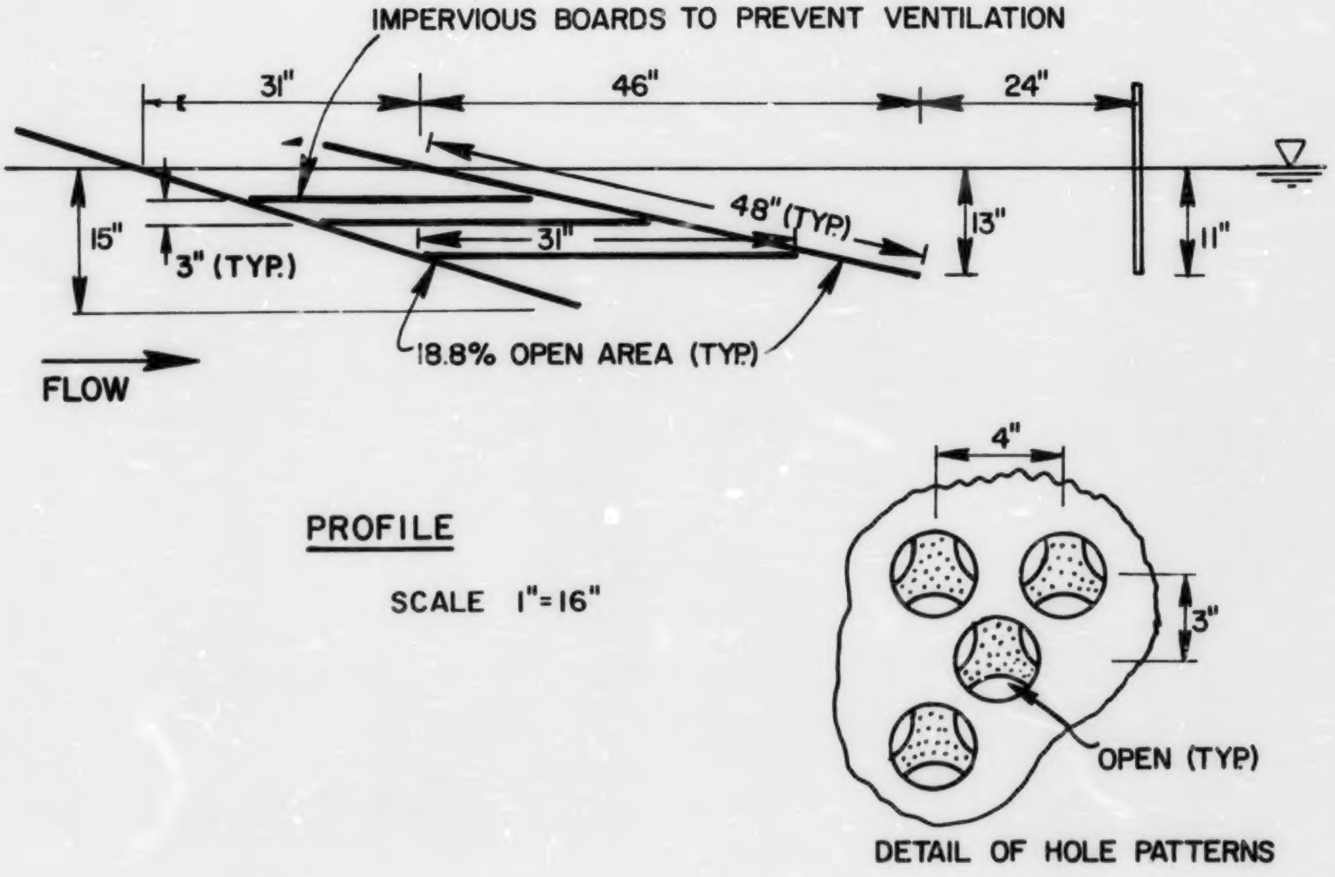

IMPERVIOUS BOARDS TO PREVENT VENTILATION
31"
46"
24"
48" (TYP.)
15"
3" (TYP.)
31"
13"
11"
18.8% OPEN AREA (TYP.)
FLOW
PROFILE
SCALE 1"=16"
4"
3"
OPEN (TYP.)
DETAIL OF HOLE PATTERNS

FIGURE B-33 - OPTIMUM INCLINED PLATE BAFFLE BOOM ARRANGEMENT BASED ON FULL SCALE TESTS IN CURRENT TANK

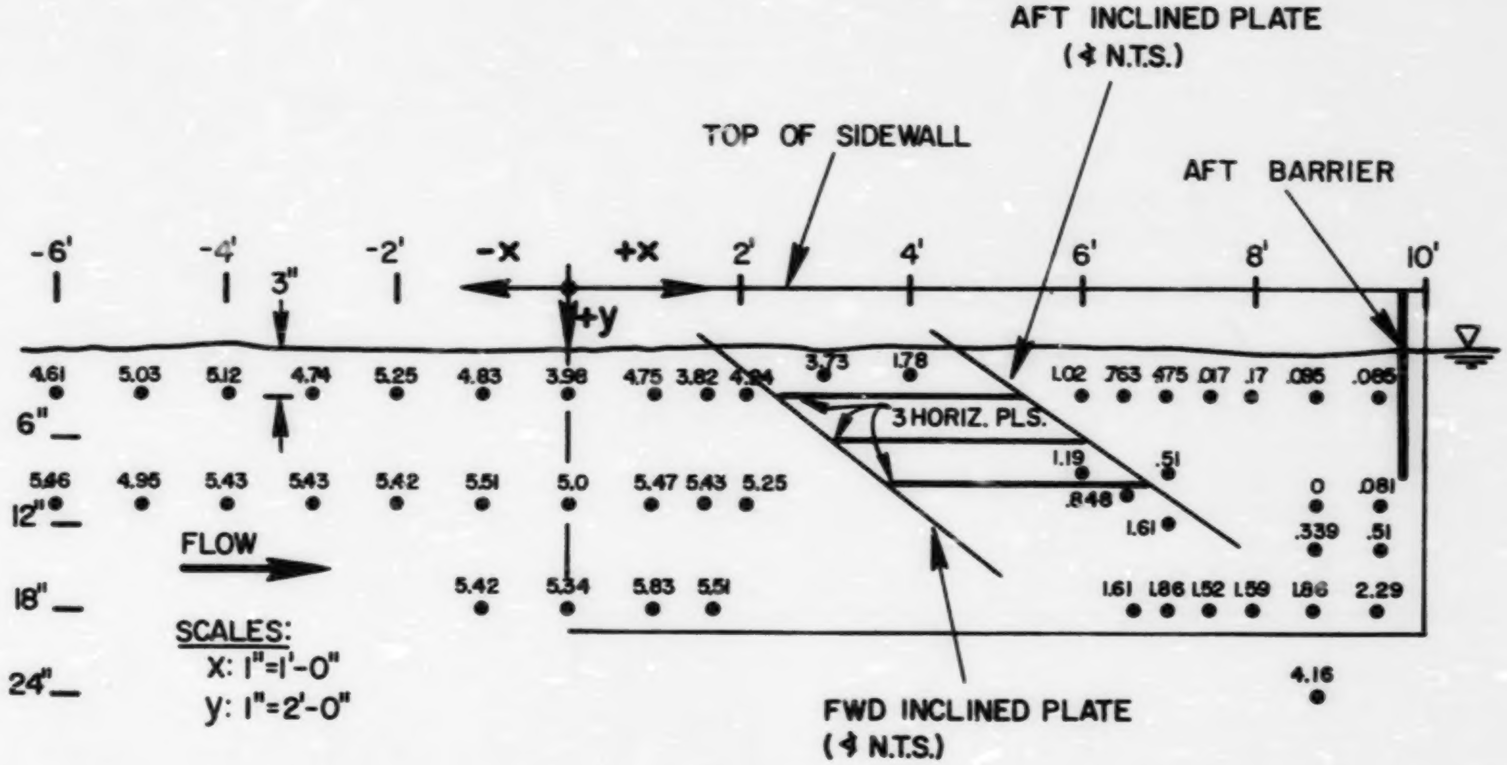
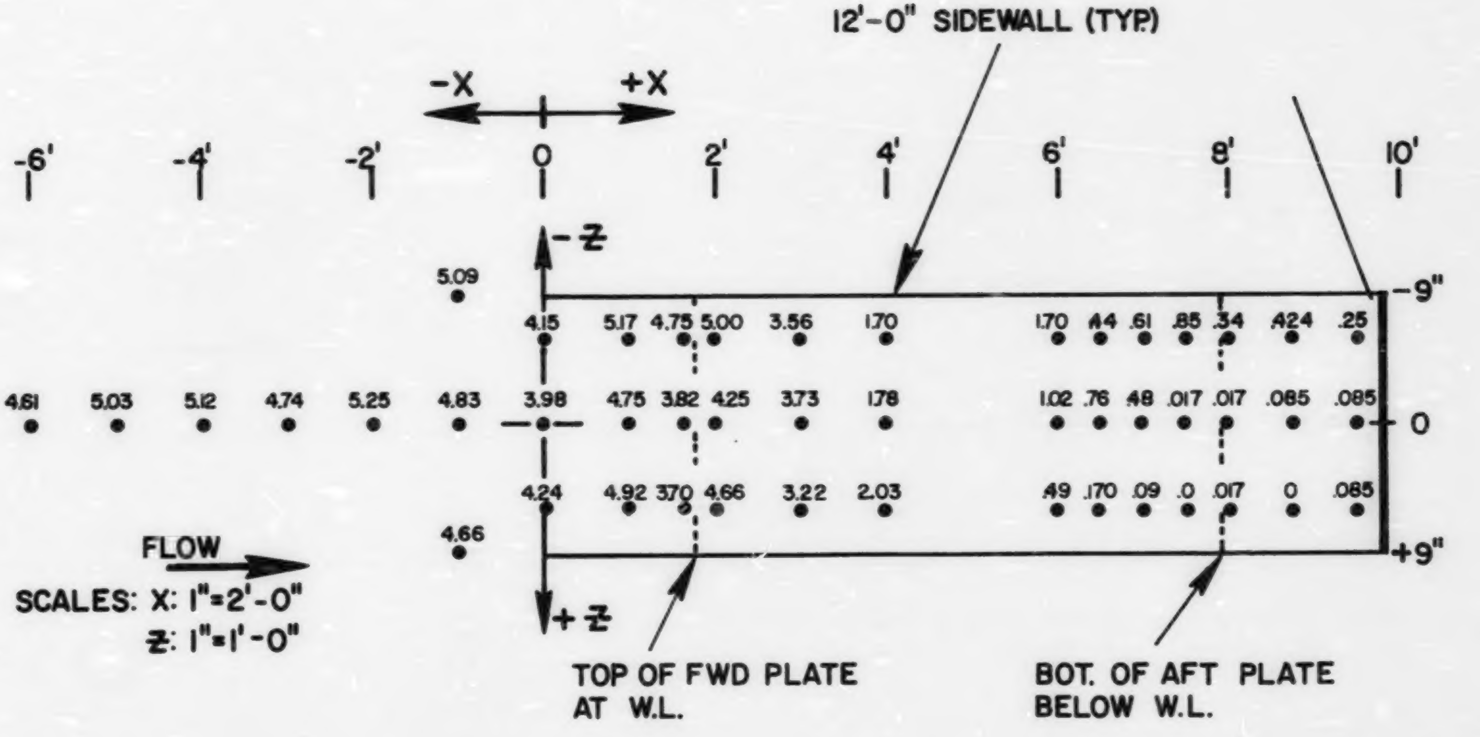

AFT INCLINED PLATE
(℄ N.T.S.)
TOP OF SIDEWALL
AFT BARRIER
-6'
-4'
3"
-2'
-x
+x
2'
4'
6'
8'
10'
+y
4.61
5.03
5.12
4.74
5.25
4.83
3.98
4.75
3.82
4.94
3.73
1.78
1.02
.763
.475
.017
.17
.086
.085
6"
3 HORIZ. PLS.
1.19
.51
5.46
4.95
5.43
5.43
5.42
5.51
5.0
5.47
5.43
5.25
.848
0
.081
12"
1.61
.339
.51
FLOW
18"
5.42
5.34
5.83
5.51
1.61
1.86
1.52
1.59
1.86
2.29
SCALES:
x: 1"=1'-0"
y: 1"=2'-0"
24"
4.16
FWD INCLINED PLATE
(℄ N.T.S.)

FIGURE B-34 - POINT VELOCITIES FOR A ℄ PLANE THROUGH INCLINED PLATE PROFILE. FREE-STREAM VELOCITY IS 4.8 FPS (2.8 KNOTS). VELOCITIES SHOWN ARE IN FPS.



12'-0" SIDEWALL (TYP.)
-X
+X
-6'
-4'
-2'
0
2'
4'
6'
8'
10'
-Z
+Z
-9"
0
+9"
5.09
4.15
5.17
4.75
5.00
3.56
1.70
1.70
.44
.61
.85
.34
.424
.25
4.61
5.03
5.12
4.74
5.25
4.83
3.98
4.75
3.82
4.25
3.73
1.78
1.02
.76
.48
.017
.017
.085
.085
4.24
4.92
3.70
4.66
3.22
2.03
.49
.170
.09
.0
.017
0
.085
4.66
FLOW
SCALES: X: 1"=2'-0"
Z: 1"=1'-0"
TOP OF FWD PLATE
AT W.L.
BOT. OF AFT PLATE
BELOW W.L.

FIGURE B-35 - POINT VELOCITIES FOR A HORIZONTAL PLANE 3" BELOW THE WATER'S SURFACE. THE FREE-STREAM VELOCITY IS 4.8 FPS (2.8 KNOTS) IN FRONT OF THE INCLINED PLATE BOOM PROFILE.

APPENDIX C

SUMMARY OF PERFORATED PLATE TOW TESTS

INTRODUCTION

These tests were run to determine the specific boom configuration that gives the greatest oil retention rate at a 2-1/2 knot tow speed without waves. The boom section shown in Figure 27 in the body to this report is to be modified in an effort to enhance its oil retention capacity. Previous tests were run with PVC beads, so these are the first ones using oil. Results are given in Table 1 of the main report.

The Shell wave/tow tank shown in Figure 33 was used for the tow and tests. The initial boom position and the test section are indicated. Figure C-1 shows the test rigging used to apply and contain oil. The test oil for this phase of tests is a Navy Distillate oil, similar to No. 2 Fuel Oil in physical properties.

TEST PROCEDURE

The procedure for each tow run is generally as follows:

1. Check wave/tow tank for accumulated oil from previous runs. If oil is present, remove it or isolate it with a boom so that oil lost from the test to be run can be separated.
2. Place the boom section and associated apparatus in the aft slip of the tow tank. Attach cables and hoses.
3. (a) If the test to be run is a "constant volume" one, slowly pour the oil into the rear area of the boom using a tear-away barrier forward to restrain the oil before the tow run.

   (b) If the test is a "constant flow rate" one, start the oil flow from the storage tank into a return sump by turning on the pump switch. After flow is initiated and after the boom reaches the beginning of the 100' test section, activate a 3-way valve to direct the flow into the hose that feeds oil in front of the boom during the tow run*
4. Start the electric powered winch to initiate the tow run. Control the speed to affect all of the acceleration before the start of the

---

* The flow has been previously calibrated by timing the oil accumulation in a 5-gallon drum.

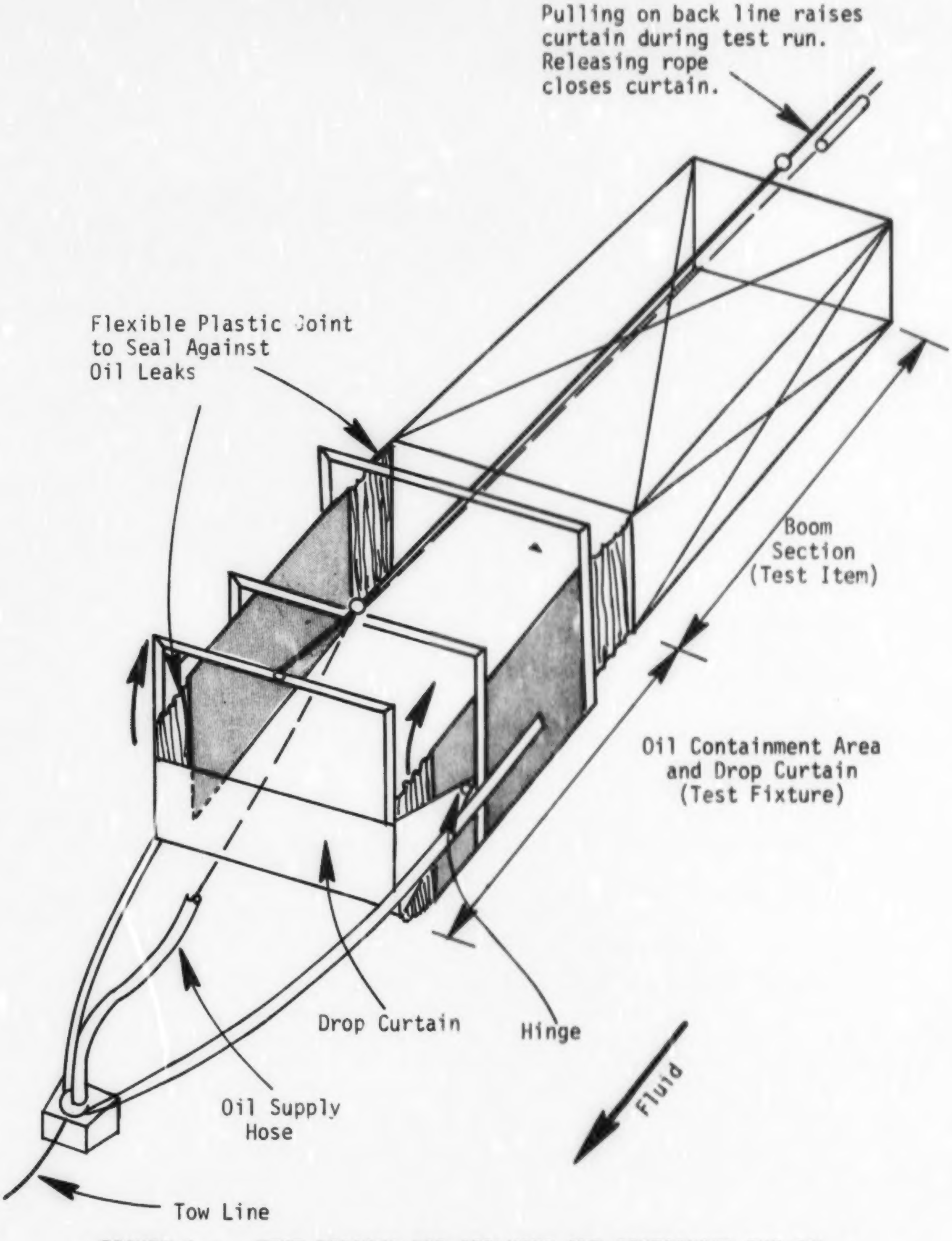

Pulling on back line raises curtain during test run. Releasing rope closes curtain.
Flexible Plastic Joint to Seal Against Oil Leaks
Boom Section (Test Item)
Oil Containment Area and Drop Curtain (Test Fixture)
Drop Curtain
Hinge
Fluid
Oil Supply Hose
Tow Line

FIGURE C-1 - TEST RIGGING FOR APPLYING AND CONTAINING THE OIL test section is reached. Hold the winch speed constant while the boom moves through the 100' test section.

5. If the run is a constant volume test, raise the curtain when the speed is high enough to force the oil to the rear barrier of the boom. If the run is a constant flow rate one, raise the curtain any time before the 3-way valve is turned to apply the oil.

6. After the boom passes the end point of the test section:

   Constant Flow Rate Test. Divert the oil flow back to the sump using the 3-way valve. After decreasing the winch speed, release the aft rope to lower the oil confining curtain.

   Constant Volume Test. Same as for Constant Flow Rate Test except omit the 3-way valve change.

7. Check to see that oil is not lost under the forward curtain during the deceleration phase. If oil is lost in front, use water hoses to separate this loss from the loss under the boom during the test run.

8. Remove the oil lost under the skimmer from the tank and measure it. Remove the oil remaining in the skimmer and measure it. Notes: (a) take care not to emulsify oil during pickup; (b) allow adequate time for gravity settling of oil in container prior to measuring the volumes of oil.

APPENDIX D

THREE-DIMENSIONAL TOW TESTS - HOUSTON

At the conclusion of the two-dimensional test program three-dimensional (diversion) tests were also conducted at Houston. Five four-foot-wide boom segments were joined side-by-side to form a 20-foot-long high-current boom. The boom was attached to the towing bridge with cables and a trailing boom was attached to the downstream end of the high-current boom to separate the oil successfully diverted during the run from that lost under (or over) the high current boom.

Oil was applied to the water in front of the advancing boom using a wide pipe manifold attached to the bridge. Equally spaced holes in the pipe allow oil to flow onto a flexible plastic curtain. The overlaping flow plumes run down the curtain onto the water creating an approximately uniform thickness oil lens about six feet wide. Normally the manifold was located to allow the oil to approach the boom at mid-length. Oil was applied to the water at a constant flow rate for a tow distance of 75 feet.

Figure D-1 shows a sketch of the test set-up in the wave tank.

The tow test conditions and results are contained in Table D-1. Notice that all of the oil diversion percentages are above 90%. By comparing the results of Table D-1 with those for the OHMSETT tests (Table 5 in the main body of this report), one finds that the results (excluding the denser Navy Special oil tests) are similar except for tow runs above 2.5 knots. At the higher speeds we feel that the Houston tank is too short (for towing wide devices) and that the oil losses under the high-current boom would be created in a longer tank.

We conclude that the OHMSETT diversion test results are more reliable than the results from this short tank. Consequently these results were not relied upon in quantitatively assessing the performance of the high-current boom in diversion.

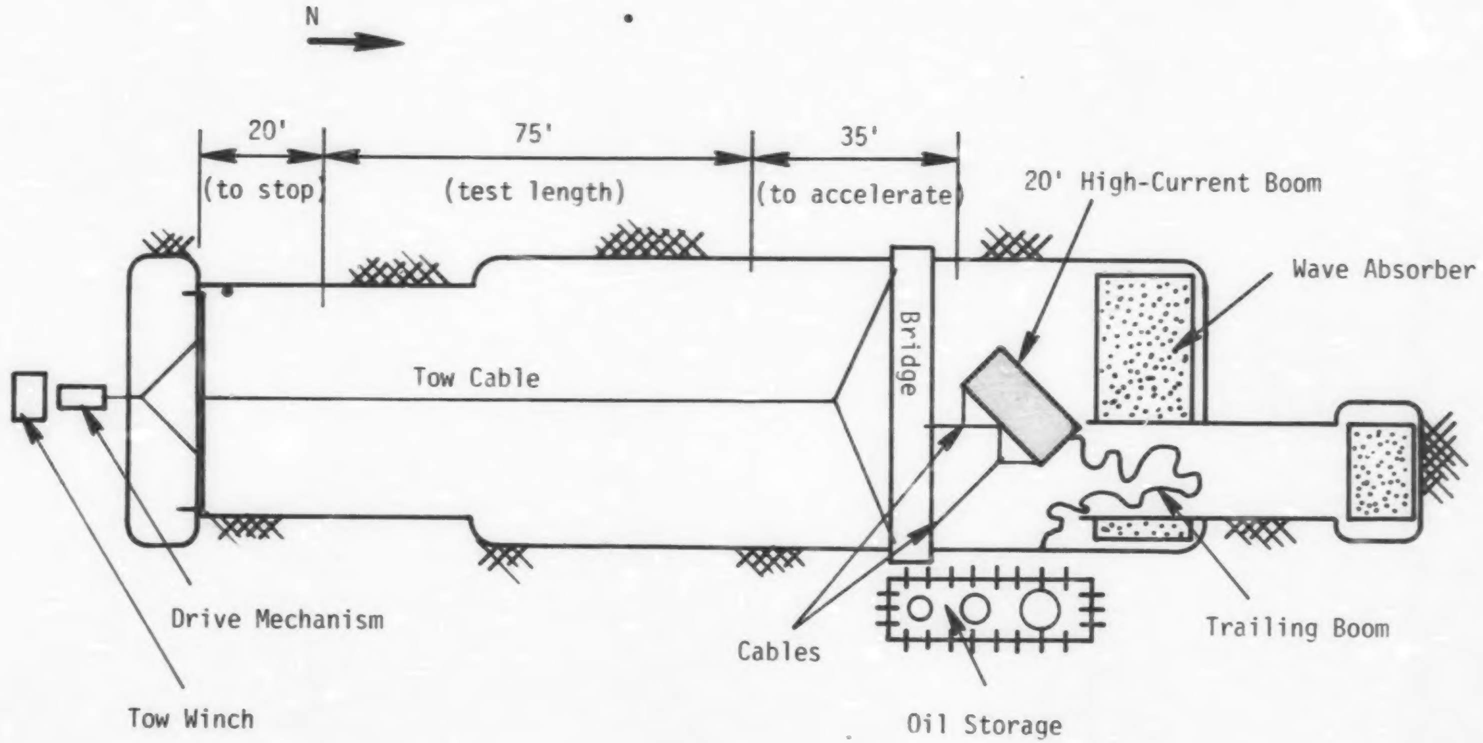

N
20'
(to stop)
75'
(test length)
35'
(to accelerate)
20' High-Current Boom
Wave Absorber
Tow Cable
Bridge
Drive Mechanism
Tow Winch
Cables
Trailing Boom
Oil Storage

FIGURE D-1 - BOOM TEST SET-UP IN HOUSTON WAVE/TOW TANK

TABLE D-1

DIVERSION TESTS OF THE EPA HIGH CURRENT BOOM

HOUSTON TANK

Run-Angle	Knots	Wave Height (ft)	Steepness Ratio (H/L)	Equiv. Slick Thickness (mm)	Percent Oil Loss
1-15°	2.4	--	--	2.3	2.6
1-30°	2.4	--	--	2.5	1.3
1-45°	2.5	--	--	2.2	0.8
1-60°	2.5	--	--	2.2	3.0
2-15°	3.0	--	--	1.9	2.0
2-30°	2.9	--	--	1.8	1.1
2-45°	3.0	--	--	1.9	2.6
2-60°	3.0	--	--	1.8	1.3
3-60°	3.6	--	--	1.6	0.9
4-15°	2.4	0.5	0.05	2.2	1.5
4-45°	2.4	0.5	0.05	2.2	2.8
5-45°[g]	2.5	--	--	--	--
6-45°[g]	2.6	0.5	0.05	2.0	9.6
7-45°[g]	2.5	1.0	0.05	2.0	9.1
8-45°[g]	2.4	--	--	2.4	3.5
9-45°	2.5	1.0	0.05	1.5	4.3[h]
10-45°	2.5	1.0	0.05	1.5	9.6[i]
11-45°	2.5	0.5	0.05	1.3	6.0[i]
12-45°	2.5	--	--	1.3	4.4[i]
13-45°	2.5	--	--	1.6	6.4[j]

NOTES:
a) Five four-ft wide boom sections were used.
b) The transverse direction is 0°, the tow direction is 90°.
c) Oil flow from the nozzle was begun at the start of the 75-ft tow line.
d) Navy Distillate was used in the tests (6 cp at 77°F).
e) Percent oil loss based on comparison of the total volume lost with the total volume applied.
f) Center of nozzle in line with center of boom, except as noted.
g) Center of nozzle moved from center of boom 4-ft toward leading edge of boom.
h) Oil applied at starting point.
i) Oil applied 10-ft before starting point.
j) Oil applied 25-ft before starting point.

APPENDIX E

OHMSETT TEST FACILITY

The U.S. Environmental Protection Agency is operating on Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) located in Leonardo, New Jersey. This facility shown in Figure E-1 provides an environmentally safe place to conduct testing and development of devices and techniques for the control of oil and hazardous materials spilled in inland and coastal waters.

The primary feature of the facility is a pile-supported, concrete tank with a water surface 667 feet long by 65 feet wide and with a water depth of 8 feet. The tank can be filled with fresh or salt water. The tank is spanned by a towing bridge which can tow loads up to 34,000 lbs. at speeds to six knots for a duration of 45 seconds. Slower speeds yield longer test runs. The towing bridge is equipped to lay oil on the surface of the water several feet ahead of the device being tested, such that reproducible thicknesses and widths of oil slicks can be achieved with minimum interference by wind.

The principal systems of the tank are a wave generator and beach, a bubbler system, and a filter system. The wave generator and absorber beach have capabilities of producing non-reflecting waves to two feet high and 80 feet long, as well as a series of reflecting, complex waves which simulate the complex water surface of a harbor or estuary. The water is clarified by recirculation through a diatomaceous earth filter system to permit underwater photography and video imagery, and to remove the few ppm of hydrocarbons that remain after a test. A bubbler system which prevents oil from reaching the tank walls, the beach, or the wave generator. This system is designed to speed cleanup between test runs, since a clean tank surface is essential to reproducible oil spill conditions. The towing bridge has a built-in skimming board which, in conjunction with the bubbler system, can move oil on to the farthest end of the tank from the generator for cleanup and recycling.

When the tank must be emptied for maintenance purposes, the entire water volume (2.6 million gallons) is filtered and treated until it meets all applicable state and federal water quality standards before being discharged.

Tests at the facility are supported from a 7,000 square foot building adjacent to the tank. This building houses offices, a quality control laboratory (which is very important since test oils and tank water are both recycled) a small machine shop, and an equipment preparation area.

OHMSETT is a government owned, contractor operated facility. The operating contractor, Mason and Hanger-Silas Mason, Co. Inc., provides a staff of eleven multidisciplinary personnel. The U.S. Environmental Protection Agency provides project guidance and expertise in the area of spill control technology.

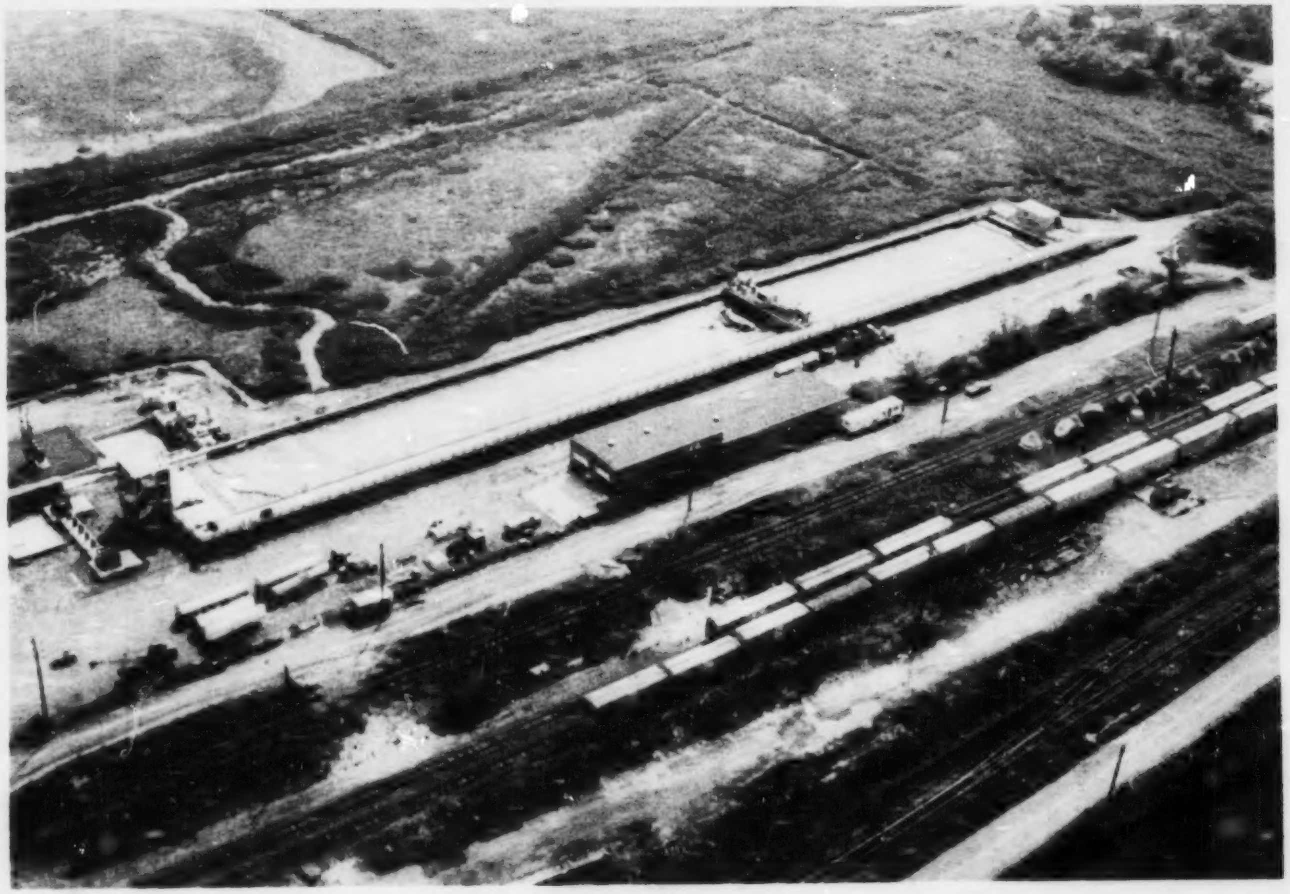


FIGURE E-1 - THE EPA WAVE/TOW TANK CALLED OHMSETT

APPENDIX F

APPLIED AND RECOVERED OIL PROPERTIES OHMSETT TESTS

Oil Type	Applied or Recovered Test #	V(cs)	Oil Temp (°F)	Sp. Gr. (g/cc)	Oil Surface Tension (dynes/cm)	Interfacial Tension Oil/Sea Water	Percent Water
Sun 75	Applied Tests 1&2	267	120	0.875	30.1	9.1	0.8
Sun 75	Applied Test 3	863.3	88	0.890	30.8	13.8	9.0
Sun 75	Recovered Test 4	-	68	-	-	-	25.0
Sun 75	Recovered Test 6	-	74	-	-	-	21.0
Sun 75	Recovered Test 5	-	75	-	-	-	25.0
Sun 75	Applied Tests 7&8	578.5	110	0.886	31.6	9.6	8.0
Sun 75	Recovered Test 7	-	73	-	-	-	30.0
Sun 75	Recovered Test 8	-	73	-	-	-	20.0
#2 Fuel	Applied Test 9&10	7.1	80	0.847	28.8	13.6	-
#2 Fuel	Recovered Test 9	-	-	-	-	-	3.0
#2 Fuel	Recovered Test 10	-	-	-	-	-	8.5

SELECTED PHOTOGRAPHS, OHMSETT TESTS

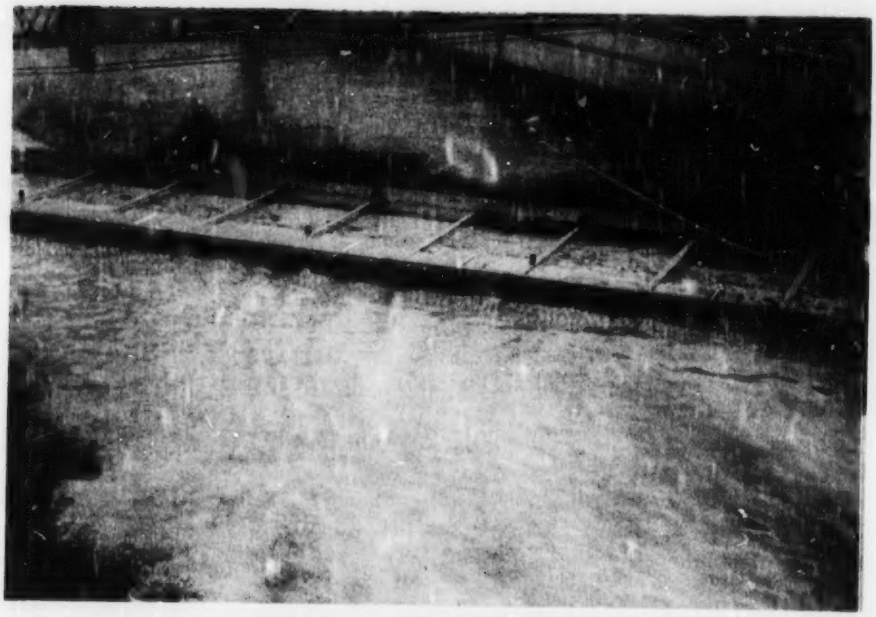


FIGURE F-1 - TEST 2. BOOM AT 45° USING SUN 75 OIL, TOW VELOCITY 3.0 KNOTS, NO WAVES

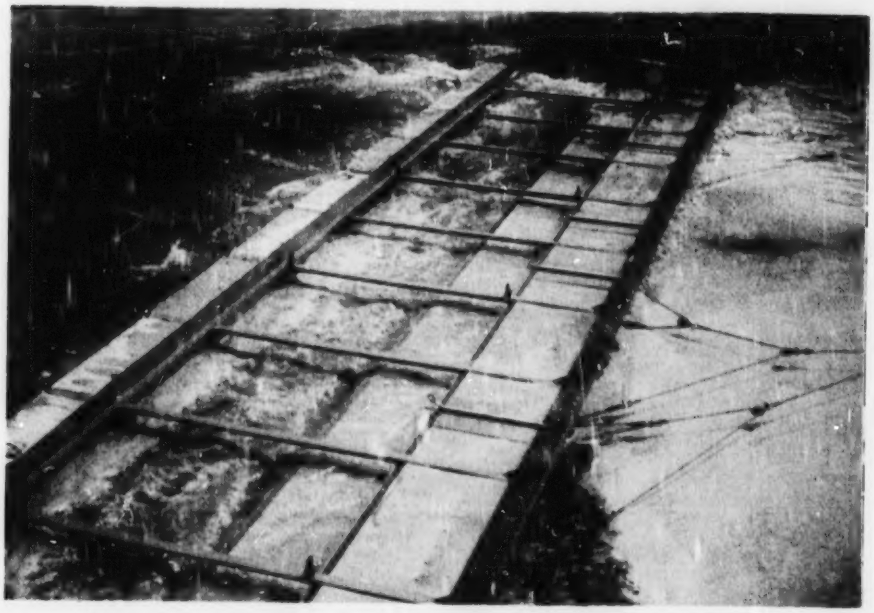


FIGURE F-2 - TEST 5. BOOM AT 45° USING SUN 75 OIL, TOW VELOCITY 3.25 KNOTS, WAVES 6" HIGH AND 3 SECOND PERIOD

SELECTED PHOTOGRAPHS, OHMSETT TESTS

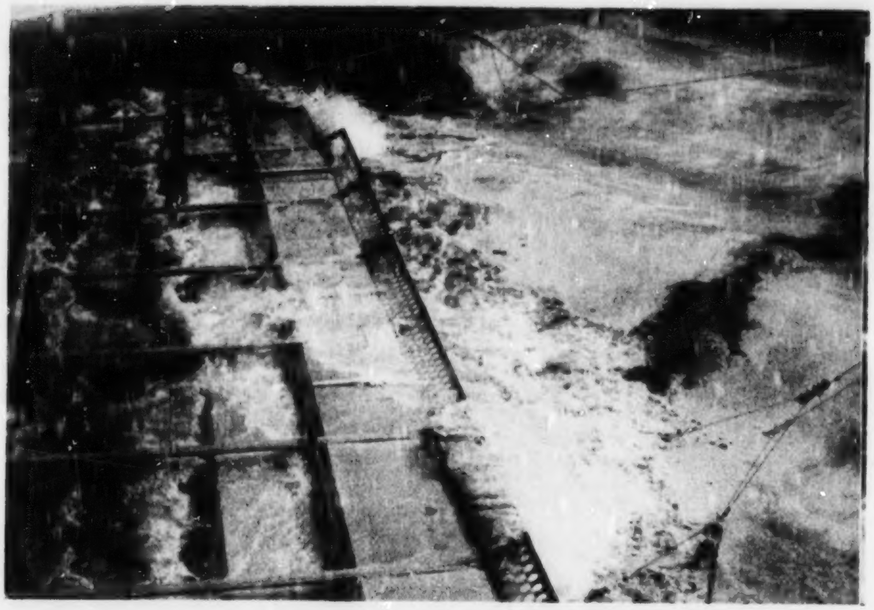


FIGURE F-3 - TEST 6. BOOM AT 45° USING SUN 75 OIL, TOW VELOCITY 3.0 KNOTS, WAVES 8" HIGH AND 2 SECOND PERIOD

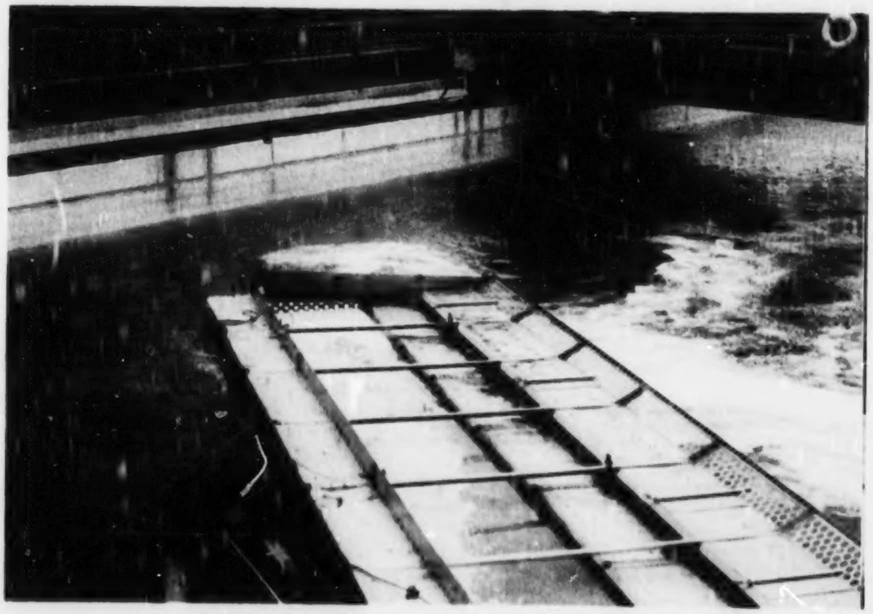


FIGURE F-4 - TEST 9. BOOM AT 45° USING NO. 2 FUEL OIL, TOW VELOCITY 3.0 KNOTS AND NO WAVES

SELECTED PHOTOGRAPHS, OHMSETT TESTS

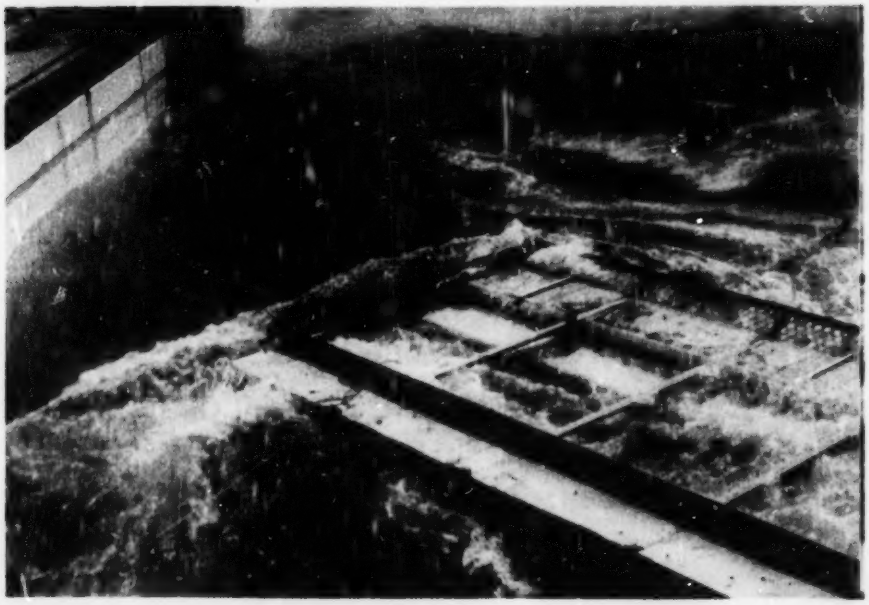


FIGURE F-5 - TEST 10. BOOM AT 45° USING NO. 2 FUEL OIL, TOW VELOCITY 3.0 KNOTS, WAVES 8" HIGH AND 2 SECOND PERIOD

APPENDIX G

ENGLISH - METRIC CONVERSION TABLE

Multiply	by	To Obtain
feet	0.305	meters
feet/second	0.305	meters/second
feet/second^2	30.480	centimeters/second^2
gallons	3.785	liters
gallons/minute	0.063	liters/second
inches	2.540	centimeters
knots	0.515	meters/second
pounds	453.600	grams
pounds/cubic foot	0.016	grams/cubic centimeter